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MEASURING THE TEMPERATURE OF GASES IN BOILER SETTINGS

BY

HENRY KREISINGER

AND

J. F. BARKLEY



WASHINGTON
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MEASURING THE TEMPERATURE OF GASES IN BOILER SETTINGS.

By HENRY KREISINGER and J. F. BARKLEY.

INTRODUCTION.

This book is one of a series of publications being issued by the Bureau of Mines for the purpose of disseminating information in regard to the methods by which the fuels in this country may be used most efficiently. A knowledge of the temperature of the gases in boiler settings and in other commercial apparatus using heat tends to develop improved designs of apparatus and better methods of operation, thus reducing waste of fuel. The following pages present, for the benefit of those designing, operating, and testing such apparatus, information as to the accuracy of temperature measurements made under certain conditions and the corrections that can be safely applied.

SCOPE OF REPORT.

This bulletin, which may be considered a companion to Technical Paper 80^a and to Bulletin 97^b is, like those two publications, intended primarily for boiler-room operators or testing engineers. Also, it may be found helpful to men in other industrial establishments where measurements of the temperatures of gases are desirable. The bulletin presents the results of a series of measurements of the temperatures of gases in the most common types of boilers, discusses the errors occurring in the usual methods of measurement, and gives directions for making and using inexpensive thermocouples to determine flue-gas temperatures. In these directions only such tools are recommended as are available in an ordinary boiler plant.

The reader should remember that the degree of accuracy of gas-temperature measurements depends more on the judgment of the user than on the correct calibration of the temperature-measuring

^a Kreisinger, Henry, and Ovitz, F. K., Sampling and analysis of flue gases: Bull. 97, Bureau of Mines, 1915, 83 pp.

^b Kreisinger, Henry, and Ovitz, F. K., Sampling and analysis of flue gases: Bull. 97, Bureau of Mines, 1915, 70 pp.

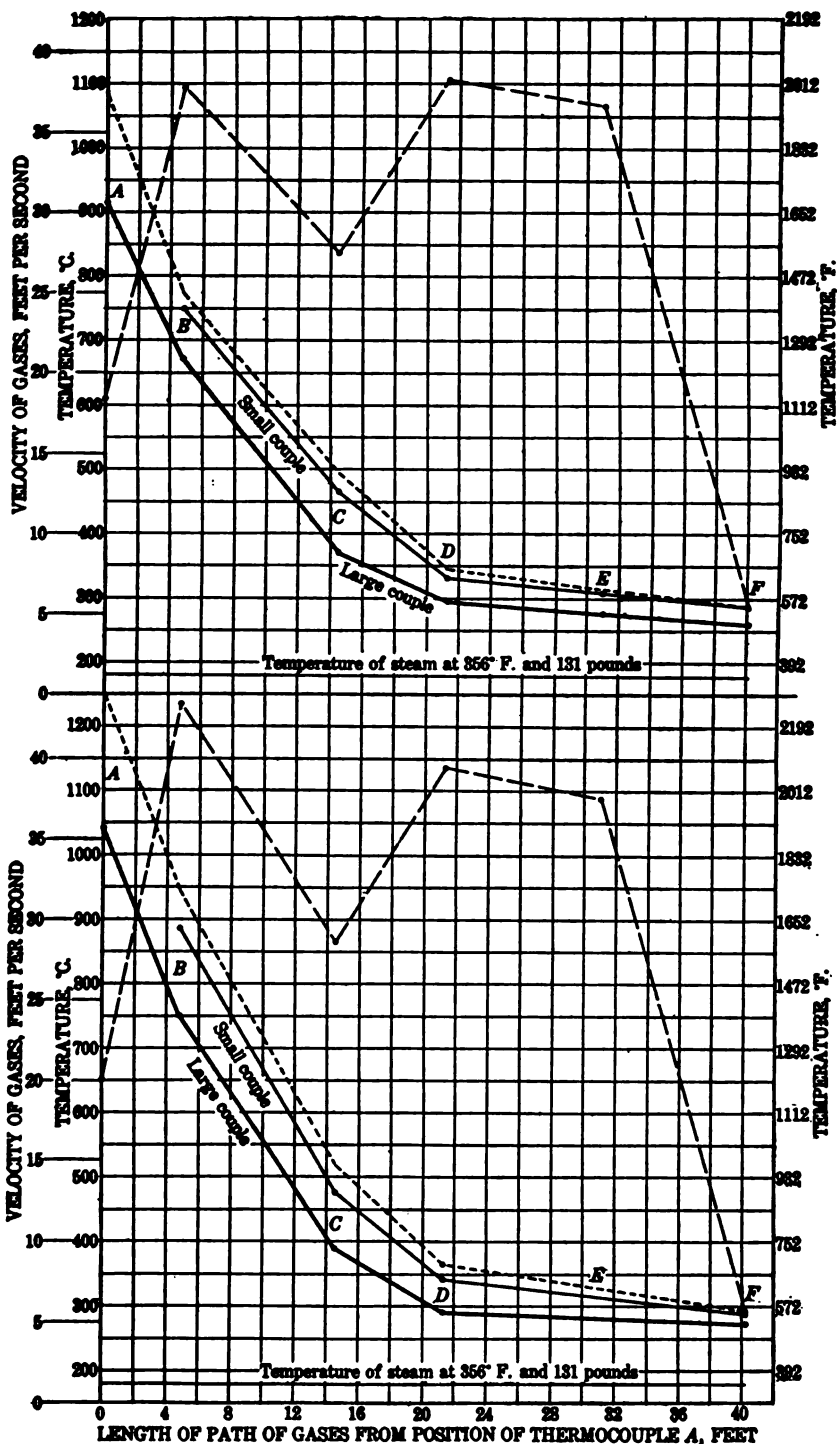
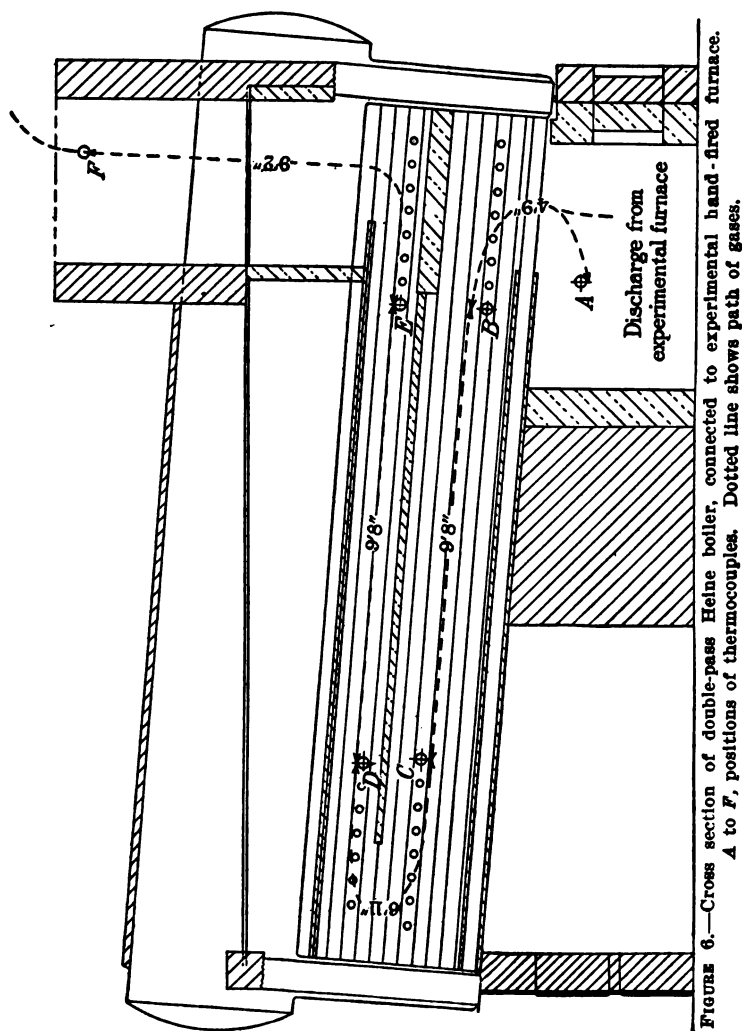


FIGURE 5.—Curves showing temperatures of gases flowing through a double-pass Heine boiler. Positions of thermocouples and path of gases are indicated in figure 6. Solid curves show temperatures indicated by couples; dotted curve, approximate true temperature of gases as computed from experimental data; dashed curve, computed velocity of gases as they pass through boiler setting. Upper and lower diagrams show similar data for two different initial temperatures.

Heating surface of tubes.....	square feet.....	1,897
Number of steam drums.....	.....	1
Length of steam drum.....	feet.....	22
Diameter of steam drum.....	inches.....	42
Approximate effective surface of drum and legs.....	square feet.....	103



TESTS WITH PARKER BOILER.

The results of experiments with a Parker boiler in the power plant of the experiment station of the Bureau of Mines at Pittsburgh, Pa., are shown in figure 7. A cross section of the boiler is shown in figure 8. The boiler was equipped with a chain-grate stoker. The positions of the thermocouples are indicated by the small circles designated A to D. The hot junctions of the couples were within 6

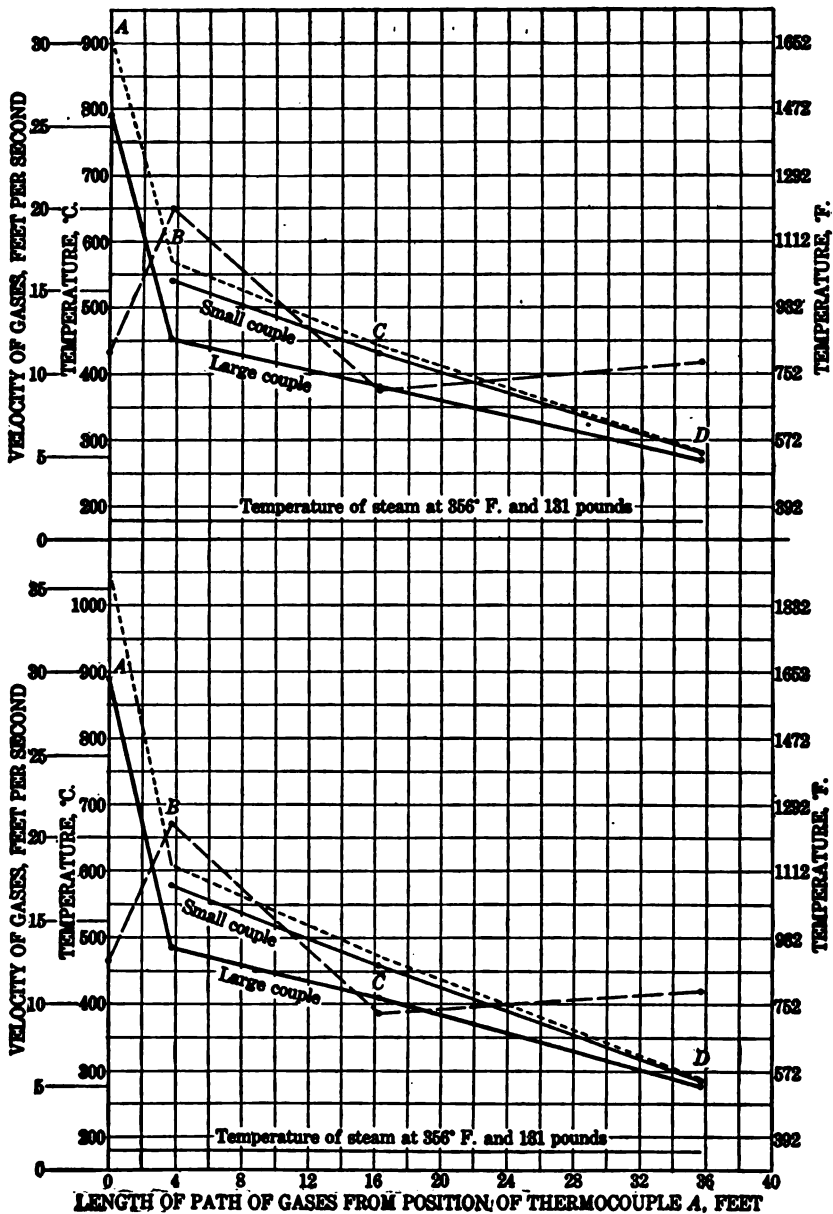


FIGURE 7.—Curves showing temperature of gases flowing through a Parker boiler. Positions of thermocouples are indicated in figure 8. Solid curves show temperatures indicated by thermocouples; dotted curves, approximate true temperature of gases as computed from experimental data; dashed curve, computed velocity of gases as they pass through boiler setting. Upper and lower diagrams show similar data for two different initial temperatures.

inches of a point midway between the side walls. The principal dimensions of the boiler are shown in the following table:

Dimensions of Parker boiler used in tests.

Total number of tubes.....	112
Number of horizontal rows.....	8
Number of vertical rows.....	14
Diameter of tubes, inches.....	4
Length of tubes, feet.....	18
Heating surface of tubes, square feet.....	2, 150
Number of steam drums.....	1
Length of steam drum, feet.....	20
Diameter of steam drum, inches.....	48
Approximate effective surface of steam drum, square feet.....	50

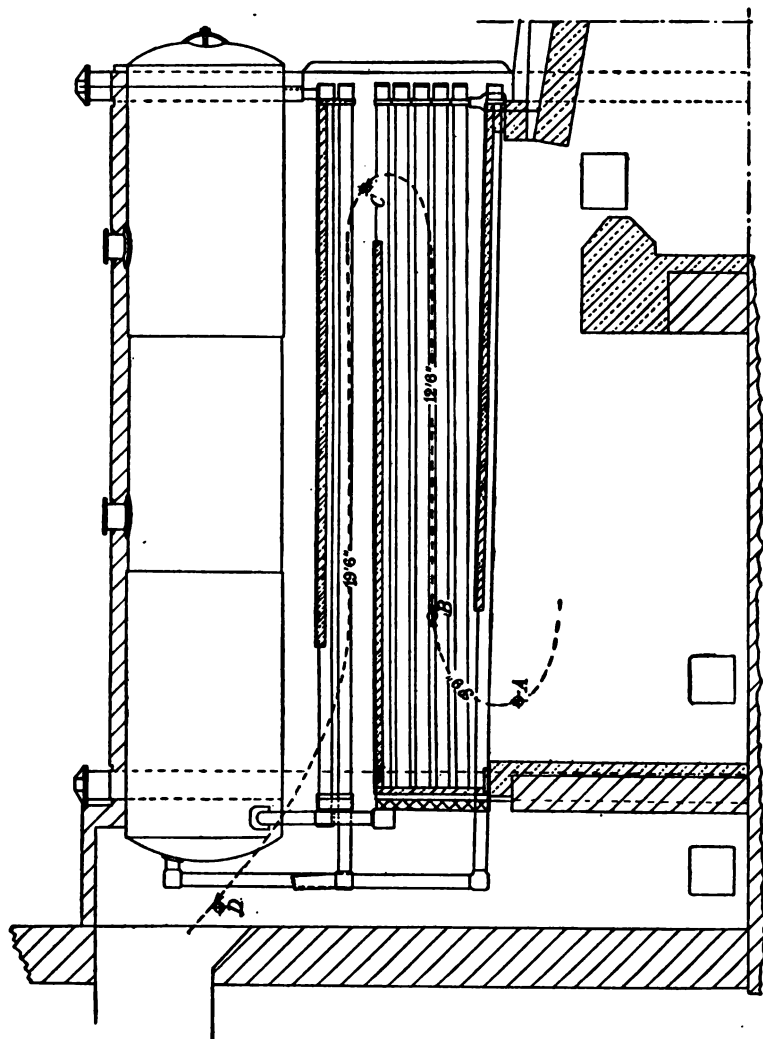


FIGURE 8.—Cross section of Parker boiler. Boiler was equipped with chain-grate stoker. A to D, positions of thermocouples. Dotted line shows path of gases.

TESTS WITH STIRLING BOILER.

Figure 9 shows results of tests with a Stirling boiler in the power plant of the Carnegie Technical Schools, Pittsburgh, Pa. A cross section of the boiler, which was fired with natural gas, is shown in figure 10. The positions of the thermocouples are indicated by the small circles designated *A* to *F*. The hot junctions of the couples were within 6 inches of a point midway between the side walls. The dimensions of the boiler were as follows:

Dimensions of Stirling boiler used in tests.

Total number of tubes.....	240
Diameter of tubes, inches.....	3½
Number of tubes across front of boiler.....	20
Total heating surface of tubes, square feet.....	2, 850
Diameter of steam drums, inches.....	42
Length of steam drums, feet.....	12½
Diameter of mud drum, inches.....	42
Length of mud drum, feet.....	10
Approximate effective surface of drums, square feet.....	200
Number of coils in superheater.....	32
Length of coils in superheater, feet.....	9
Diameter of pipe in coils of superheater, inches.....	4

DESCRIPTION OF THERMOCOUPLES USED TO DETECT RADIATION ERROR.

In the measurement of temperatures two kinds of couples were used: Copper-constantan couples for temperatures below 500° C., and platinum and platinum-rhodium couples for all temperatures higher than 500° C. Two of the same kind of couples were clamped together. In each of these twin couples the wires of one couple at the hot junction were 0.008 inch in diameter, and the hot junction of the other couple consisted of tubes approximately 0.5 inch in diameter. The construction of the twin couples is shown in figure 11; the upper half of the figure represents the copper-constantan twin couple, and the lower half the platinum and platinum-rhodium twin couple.

The leads of the small couples of both kinds were made of wires 0.025 inch in diameter. To one end of these wires were welded small pieces of wire 0.008 inch in diameter, these small wires forming the hot junctions. The object of using heavier wire beyond about half an inch from the hot junction was to strengthen the couple and to prevent sagging of the exposed part. The thicker wires were insulated with small porcelain tubes. In the copper-constantan couples these tubes were placed in standard ¾-inch iron pipe, and extended the full length of the couple, to the cold junction. In the small platinum couple the porcelain tubes were placed in a short piece of fused silica tube fitted into the end of a water-cooled holder about

5 feet long. The holder was made of three concentric thin-walled copper tubes. The smallest of these contained the thermocouple wires with their insulating porcelain tubes. By proper connections water entered the annular space between the inner and the middle copper tube, flowed to the hot end, and returned between the middle and the outer tube to the outlet.

The outside tube was only three-fourths inch in outside diameter, making the holder of convenient size for manipulation. These water-cooled holders took the place of expensive and brittle porcelain tubes, which would have broken easily when used under the given conditions, and served their purpose well.

The large copper-constantan couple was made of a copper tube 0.550 inch in outside diameter and having a wall 0.012 inch thick. Into one end of this tube was rolled a cup-shaped copper plug. The hot junction was made by peening into this plug a constantan wire 0.025 inch in diameter. This wire was led through the copper tube, from which it was insulated with glass tubing, to the cold junction placed at the other end of the copper tubing. This method of making the hot junction was mechanically satisfactory and calibration before and after the couple was used showed that its thermal electromotive force remained constant. The outside surface of the copper tube and the surface of the copper plug at the end of it received and radiated the heat.

The large platinum couple was made of wires 0.025 inch in diameter insulated by small porcelain tubes. The hot-junction end of the couple was placed in a silica tube, 0.450 inch in outside diameter and about 11 inches long, and having one end closed. The open end of this tube was fitted into a water-cooled holder as described in the preceding paragraphs. The outside surface of the tube received and radiated heat, so that, neglecting the difference in the coefficient of emissivity, the reading obtained with this construction was about the same as would have been obtained with a couple made of a large platinum tube similarly to the large copper-constantan couple. The silica tube was sufficiently long that the temperature drop due to heat conduction along the tube to the water-cooled holder was so small as to be negligible. It is well to state in this connection that the Bureau of Standards, when calibrating thermocouples at high temperatures, uses an immersion of 25 cm., or about 9 $\frac{1}{2}$ inches.

The cold junction of each couple was placed in a water bath contained in a glass vessel clamped to the cold end of the couple. The vessel, a piece of glass tubing 2 inches in diameter and about 6 inches long, was closed at both ends with rubber stoppers having perforations in which were inserted small glass tubes extending from one stopper to the other. Through the small glass tubes were passed the wires of the couples, the cold junction being placed midway between the two stoppers. From the cold junctions the copper connections

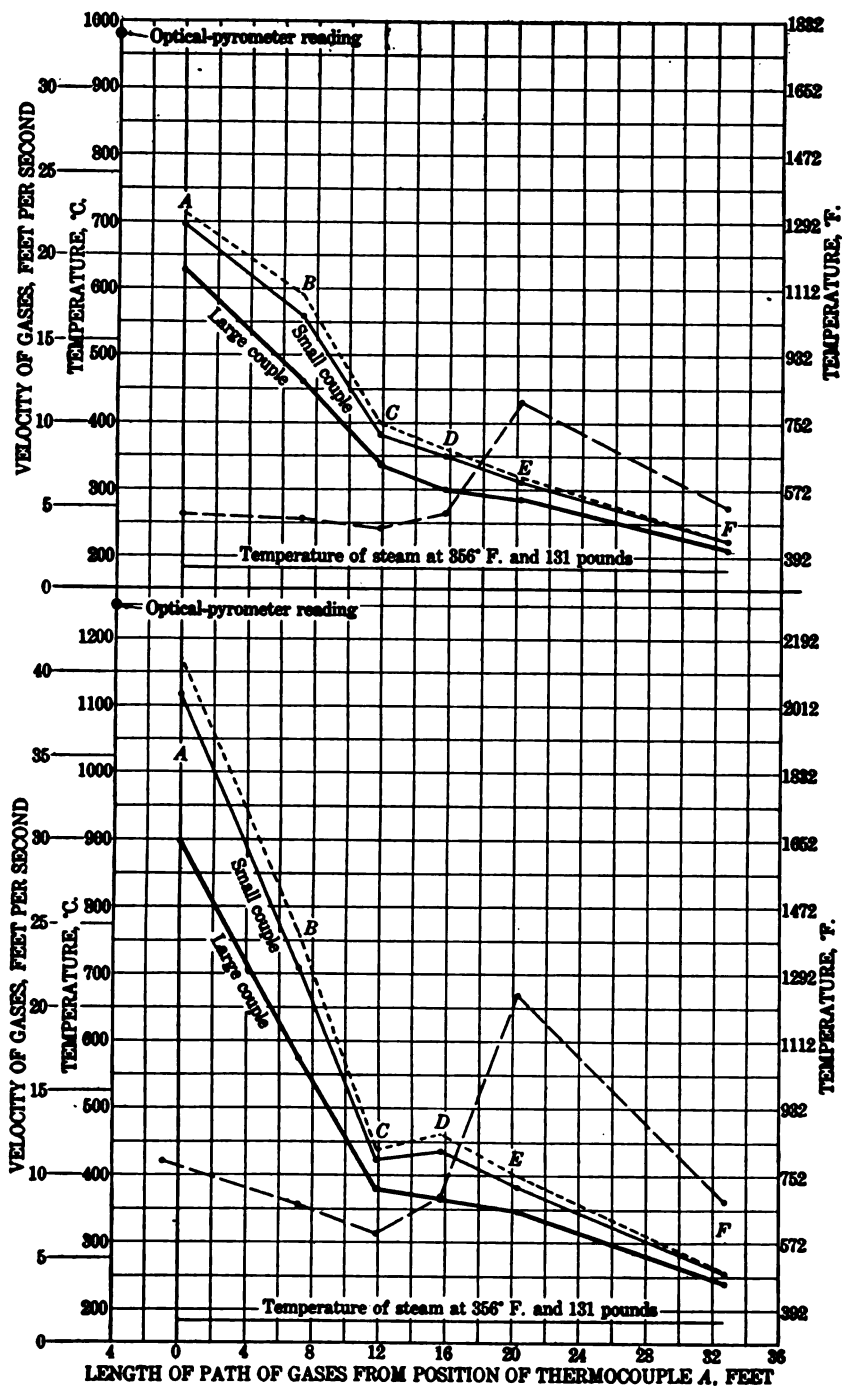


FIGURE 9.—Curves showing temperatures of gases flowing through a Stirling boiler. Positions of thermocouples are indicated in figure 10. Solid curves show temperature indicated by thermocouples; dotted curve, approximate true temperature of gases as computed from experimental data; dashed curve, computed velocity of gases as they pass through boiler setting. Upper and lower diagrams give similar data for two different initial temperatures. Large dot shows temperature of bridge wall as measured by optical pyrometer sighted through one of the burners.

were led to binding posts fastened to a fiber board. A thermometer was inserted through the free end stopper for the purpose of measuring the temperature of the bath.

A portable Leads & Northrup potentiometer was used to read the millivoltage of the couples, thus giving the temperatures.

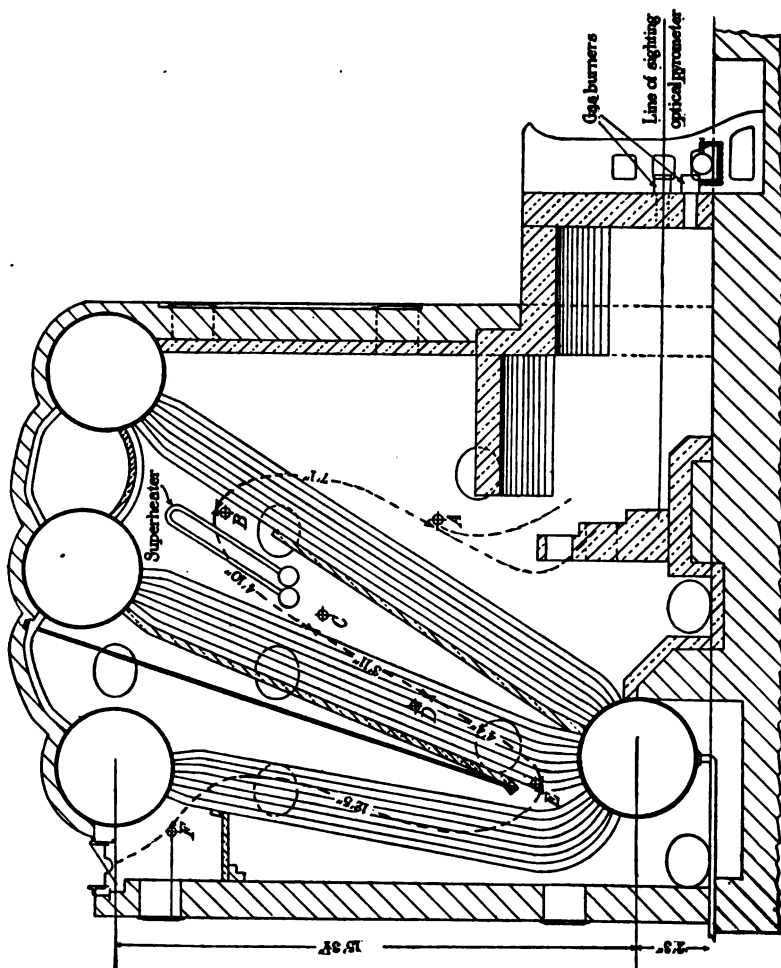


FIGURE 10.—Cross section of Stirling boiler, fired with natural gas. A to F, positions of thermocouples. Dotted line indicates path of gases.

REDUCING THE RADIATION ERROR BY SCREENING THE INSTRUMENT.

The radiation error can be reduced by screening the instrument from direct exposure to cold surfaces. The screens must be placed between the instrument and the cold surfaces in such a way that the hot gases come in contact with both sides of the screen. Screens of this kind were used in many of the steaming tests made by the Bureau of Mines and are fully described in Bulletin 23^a and Bulletin 97.^b

^a Breckenridge, L. P., Kreisinger, Henry, and Ray, W. T., Steaming tests of coal and related investigations: Bull. 23, Bureau of Mines, 1912, pp. 32-33.

^b Kreisinger, Henry, and Ovitz, F. K., Sampling and analysis of flue gases: Bull. 97, Bureau of Mines, 1915, p. 48.

By the use of such screens the radiation error can be reduced to less than one-half of the unprotected instrument. However, in many types of commercial apparatus the use of screens in making temperature measurements is impracticable.

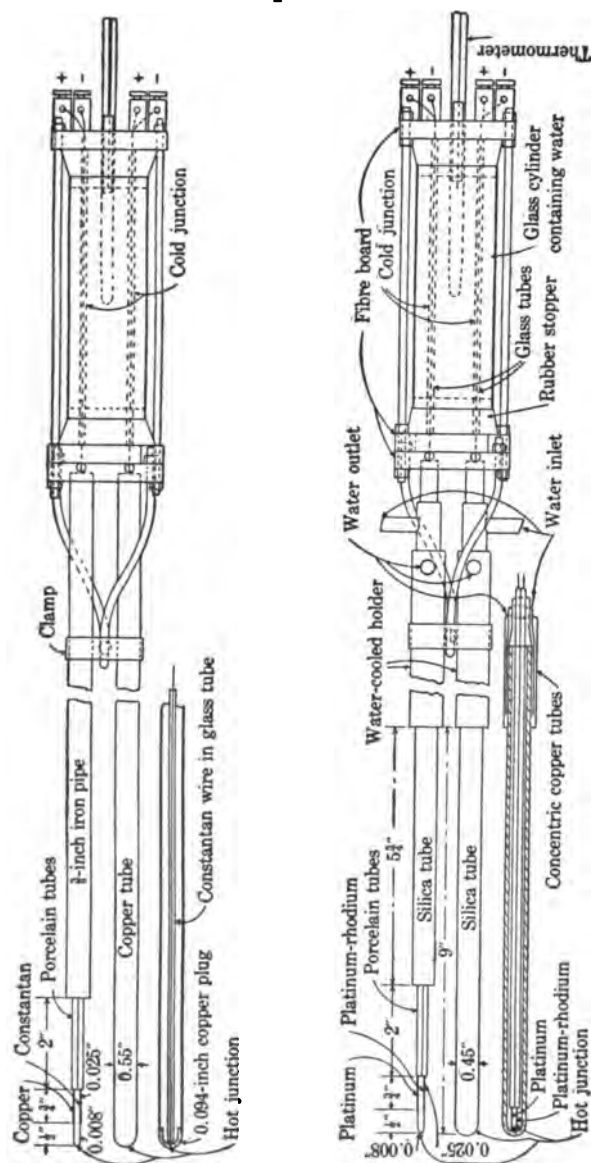


FIGURE 11.—Construction of twin couples used in temperature measurements shown in figures 1, 3, 5, 7, and 9. Upper half of the figure shows construction of the copper-constantan twin couples; lower half shows the construction of the platinum and platinum-rhodium twin couples.

DISADVANTAGE OF USING EXPOSED COUPLES.

It has been shown in the preceding discussion that a thermocouple having its hot junction exposed to the gases has a much smaller radiation error than one protected by a porcelain or a fused

silica tube. The use of the exposed couple has the drawback of the metal being liable to contamination if the gases are not clean. The impurities in the gases may combine with the metal, thus changing its nature. Carbon monoxide will form carbides with platinum, but will not affect a copper-constantan couple. The danger of the exposed part of the couple being contaminated is particularly serious when the temperature of very hot gases containing slag-forming constituents is being measured as in all apparatus using coal as fuel, and in metallurgical furnaces where the gases may contain fumes from the molten metal. Prolonged use of an exposed couple under such conditions is sure to impair its accuracy. If it is desirable to use an unprotected couple it should not be left in the gases any longer than is necessary to take a reading. The thermocouple junction, being very small, is heated to full temperature almost instantaneously, so that the reading can be taken immediately after the couple is inserted into the stream of gases; it should then be withdrawn. If the products of combustion are clean gases, such as result from the burning of natural gas, such precautions are not necessary.

A copper-constantan couple that was placed in flue gases, as suggested on page 57, showed no change in calibration, even after the wires were partly oxidized by several months of use.

VARIATION OF TEMPERATURE OF GASES AT DIFFERENT POINTS IN THE SAME CROSS SECTION.

Even though it may be possible by the use of a fine couple to obtain the correct temperature of the gases at any one point, obtaining the average temperature of the gases at any given cross section of their path is difficult, because the temperature may vary widely at different points of the same cross section. These variations are due chiefly to stratification of the gases, unequal cooling, and perhaps infiltration of air which tends to cool the gas next to the wall.

Variations in temperature between different points of the same cross section of a boiler setting are shown in figures 12 to 15.

EXPERIMENTS WITH BABCOCK & WILCOX BOILER.

Figure 12 shows the variation obtained when the twin couples at *E* and *G* in the Babcock & Wilcox boiler (see fig. 2, p. 13) were moved in equal steps from their central position. The twin couple at *E* was moved 1 inch at a time over a distance of 1 foot and the temperature indicated by both the small and the large couple was read for each position. The upper two curves of the figure represent these temperature readings, the small couple reading higher than the large one. The small couple showed two kinds of variation: A small drop in temperature for every 6 or 7 inches, corresponding

probably to the spacing of the tubes, and a constant gradual drop of temperature as the couples were moved nearer to the wall. The large couple shows only this latter variation.

The twin couple at *G* was moved in steps of 6 inches. With this couple only the constant drop in temperature is apparent, the variation due to spacing of tubes not being noticeable.

The couples were moved and the readings taken in rapid succession, the entire series with each couple not taking more than 4 or 5 minutes. During these measurements the furnace conditions were kept constant, which was comparatively easy because of the control of the gas burners.

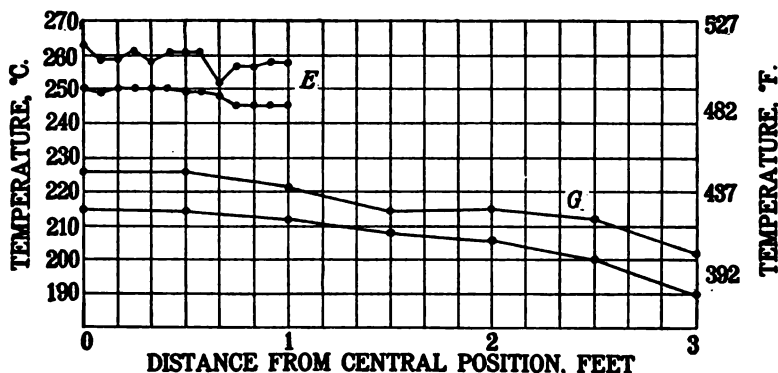


FIGURE 12.—Curves showing variations of temperature at different points of the same cross section in a Babcock & Wilcox boiler fired with natural gas. Upper pair of curves represents temperatures obtained by moving twin couple at *E* 1 inch at a time from central position; lower pair, temperatures obtained by moving twin couple at *G* 6 inches at a time. Upper curve of each pair represents temperature indicated by small couple; lower curve, temperature indicated by large couple.

EXPERIMENTS WITH STIRLING BOILER.

Figure 13 shows the variation in temperature when the twin couple at *D* in the Stirling boiler (see fig. 10, p. 23) were moved 1 inch at a time from its central position. The upper curve gives the temperatures indicated by the small couple, and the lower curve, the temperatures shown by the large couple. Both couples show temperature variation apparently due to the spacing of the tubes, and also a gradual temperature drop as the hot junctions are moved away from the center. While these readings were taken the furnace conditions were kept as nearly constant as possible by using the same number of gas burners with the same adjustment. The highest and the lowest temperatures recorded by either of the couples differ by 50° C., whereas the small couple always read about 50° C. higher than the large one. These variations show how little dependence can be placed on a reading obtained with a thermocouple inserted at random into a boiler setting.

EXPERIMENTS WITH SINGLE-PASS HEINE BOILER.

Figure 14 shows the temperature variation when the small couples at *B* and *C* in the standard single-pass Heine boiler, shown in figure 4 (p. 15), were moved in steps of 6 inches, the couples being placed in the same stay-bolt holes as they were for obtaining the data shown by the curves in figure 3 (p. 14). These 6-inch steps are indicated in figure 4 by the small circles.

Couple *B* showed a considerable range of temperature variation. The maximum temperature, which was at a point about 2 feet from

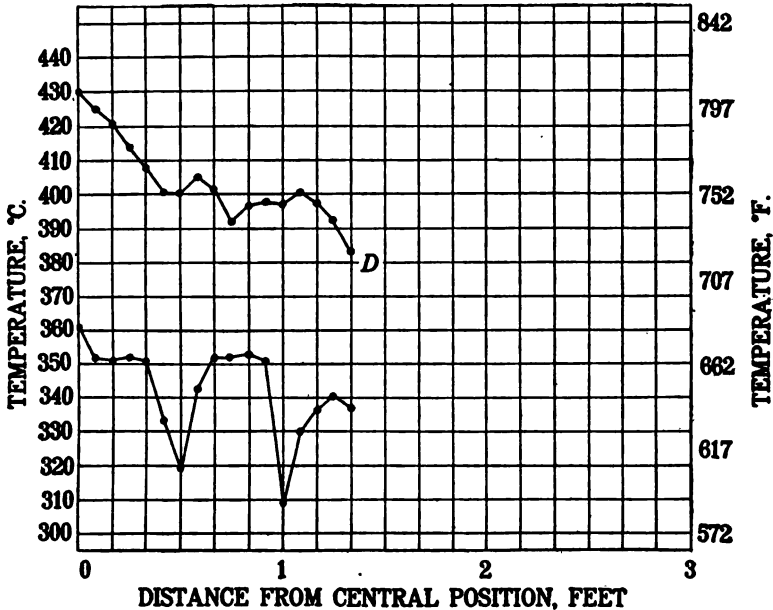


FIGURE 13.—Curves showing variations of temperature at different points of the same cross section in a Stirling boiler fired with natural gas. Readings were obtained by moving the twin couple at *D* 1 inch at a time from its central position. Upper curve represents temperature indicated by small couple; lower curve, temperature indicated by large couple.

the inside of the water leg, was 430°C . higher than that at a point 4 feet from the water leg. This wide variation was undoubtedly caused by the position of the end of the lower baffle and the sudden turn of the gases. It seems that immediately above the lower baffle there was a layer of comparatively inert gas which had a temperature much lower than that of the stream of moving gases.

Couple *C* showed a steady rise in temperature as the hot junctions were moved away from the water leg, but after a point about 2 feet from the water leg was reached the temperature remained nearly constant. The extreme variation in temperature shown by this couple was about 200°C .

EXPERIMENTS WITH DOUBLE-PASS HEINE BOILER.

Figure 15 shows the temperature variation under similar conditions in the two-pass Heine boiler attached to the hand-fired experimental furnace. Although with this apparatus the furnace conditions could not be kept as constant as with the Jones underfeed stoker, the thermocouples when moved into different position showed less variation in temperature than was found in the single-pass Heine boiler with the Jones stoker. The extreme variation shown by the couple at *D* was about 100° C. This smaller temperature variation was probably due to the higher velocity of the gases, which facili-

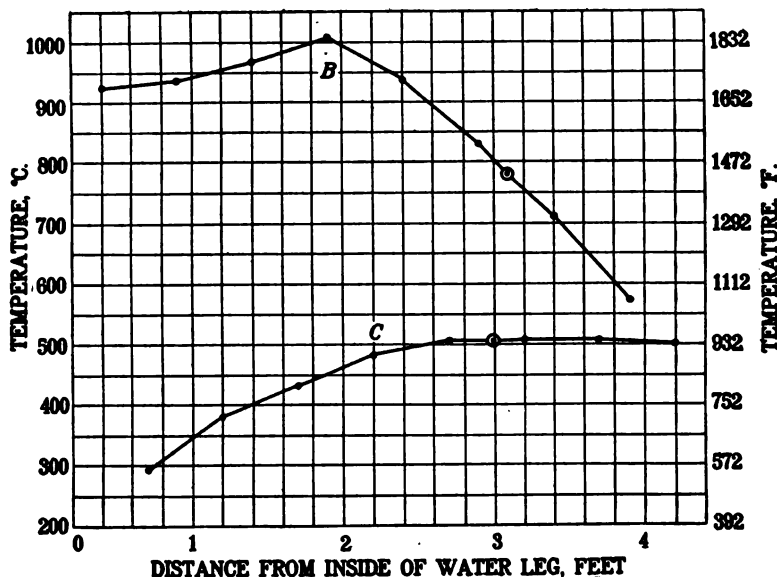


FIGURE 14.—Curves showing variations of temperature at different points in a standard single-pass Heine boiler equipped with a Jones underfeed stoker. Upper curve was obtained by moving small couple at *B* in 6-inch steps to a point 4 feet from inside of water leg; lower curve, by moving small couple at *C* in same way. Positions for each reading are shown by the small circles in figure 4; furnace conditions were kept as uniform as possible. Large circles on curves show positions of couples when data for figure 3 (p. 14) were obtained.

tated mixing and therefore a more uniform temperature. Readings were taken only with the small couples. The position for each reading is indicated in figure 6 (p. 17) by the small circles.

No readings for different position of the hot junctions were taken in the Parker boiler.

FLUCTUATION OF TEMPERATURE AT ANY ONE POINT.

The temperature of the gases at any one point in the boiler setting may fluctuate rapidly over a wide range, even though the furnace

conditions may be kept very uniform. The fluctuations in temperature obtained by taking readings every 2 seconds with two of the

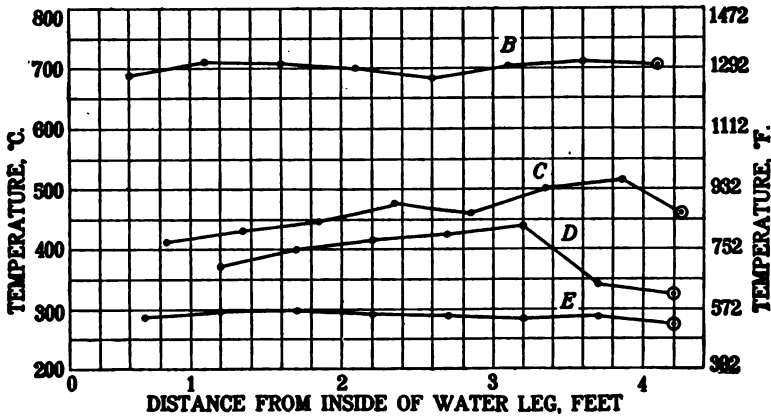


FIGURE 15.—Curves showing variations of temperature at different points in a double-pass Heine boiler receiving hot gases from a hand-fired experimental furnace. The four small couples, *B*, *C*, *D*, and *E*, were moved into different positions (shown in fig. 6, p. 17, by the small circles) 6 inches apart and a reading was obtained for each position. Each curve gives temperature indicated by couple designated by the letter. Large circles at right end of curves show positions of couples when data for figure 5 (p. 16) were obtained.

small couples in the Babcock & Wilcox boiler are shown in figure 16. The upper curve connects points representing readings taken with

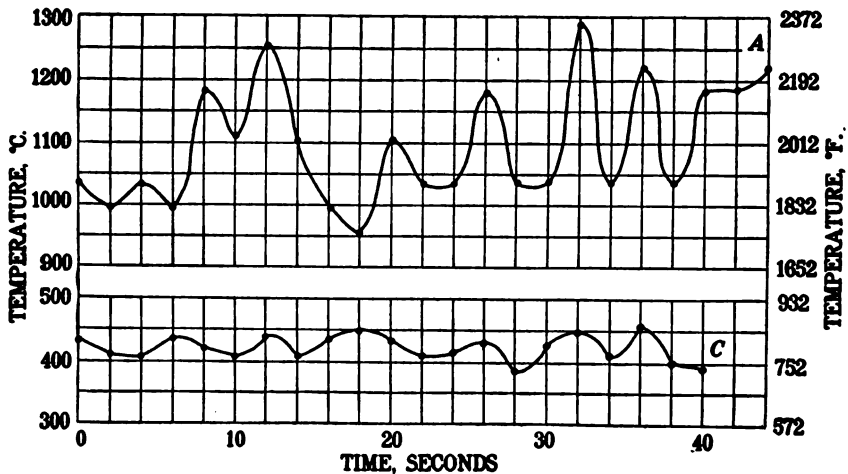


FIGURE 16.—Curves showing fluctuations of temperature at points *A* and *C* in the Babcock & Wilcox boiler shown in figure 2 (p. 13). The fluctuations were obtained by reading the small couples every 2 seconds.

the small thermocouple of the twin couple at *A* (fig. 2) and the lower curve those obtained from readings taken with the small couple of the twin couple at *C* (fig. 2). The two series of readings were

not taken simultaneously, the readings for the lower curve being taken immediately after the readings for the upper curve, but the furnace conditions were kept the same for both series. Only the small couple of each twin showed large fluctuations, the temperature indicated by the large couple, which was noted whenever a reading was made with the small couple, being nearly constant and considerably below the average of that indicated by the small couple. The maximum temperature fluctuation shown by the couple at *A* was about 300° C., the average temperature being about $1,100^{\circ}$ C. The couple at *C* showed a temperature fluctuation of about 50° C. and an average temperature of 425° C. This smaller fluctuation was partly due to the lower average temperature and partly to more complete mixing of the gases.

TEMPERATURE DROP OF GASES IN FLOWING THROUGH BOILERS.

TEMPERATURE DROP THROUGH TUBE OF A HORIZONTAL TUBULAR BOILER.

The temperature measurements given in figures 1, 3, 5, 7, and 9 afford a rough comparison of the temperature drop through the various types of water-tube boiler. In order to make this comparison more complete, the temperature drop of the gases passing through a tube of a gas-fired horizontal tubular boiler is shown in figure 17.

The data for the lower set of curves of figure 17 were taken when the initial temperature of the gases was $1,200^{\circ}$ C. and the boiler was developing 1 boiler-horsepower on about 5 square feet of heating surface. The upper set of curves is based on data obtained with an initial temperature of 800° C. and when the boiler was generating 1 boiler horsepower on 15 square feet of heating surface. The boiler was operated under a pressure of 120 pounds gage. The boiler tubes were $2\frac{1}{4}$ inches in inside diameter and 20 feet long. Temperature measurements were taken in one of the tubes, at the points indicated in figure 17 by the black dots, with a platinum and platinum-rhodium couple having an exposed hot junction 0.012 inch in diameter. Only the temperatures obtained in the center of the tube are given in the charts, although readings were taken at nine different points along a vertical diameter. The true average temperature of the gases as they passed through the tube was determined partly from the temperature of the gases entering the tube, partly from the average temperature of the gases after they left the tube and partly by correcting for radiation error the measured temperature in the tube. The average velocity of the gases was calculated from their average temperature and from the weight of air and natural gas used as measured with an orifice and a gas meter before the air and gas were fed into the furnace. The average temperature is correct to within less than 5 per cent and the average velocity to within less than 10 per cent.

Near the furnace end of the boiler tube the true average temperature was higher than the indicated temperature at the center of the cross section of the tube. The fact that the true temperature was

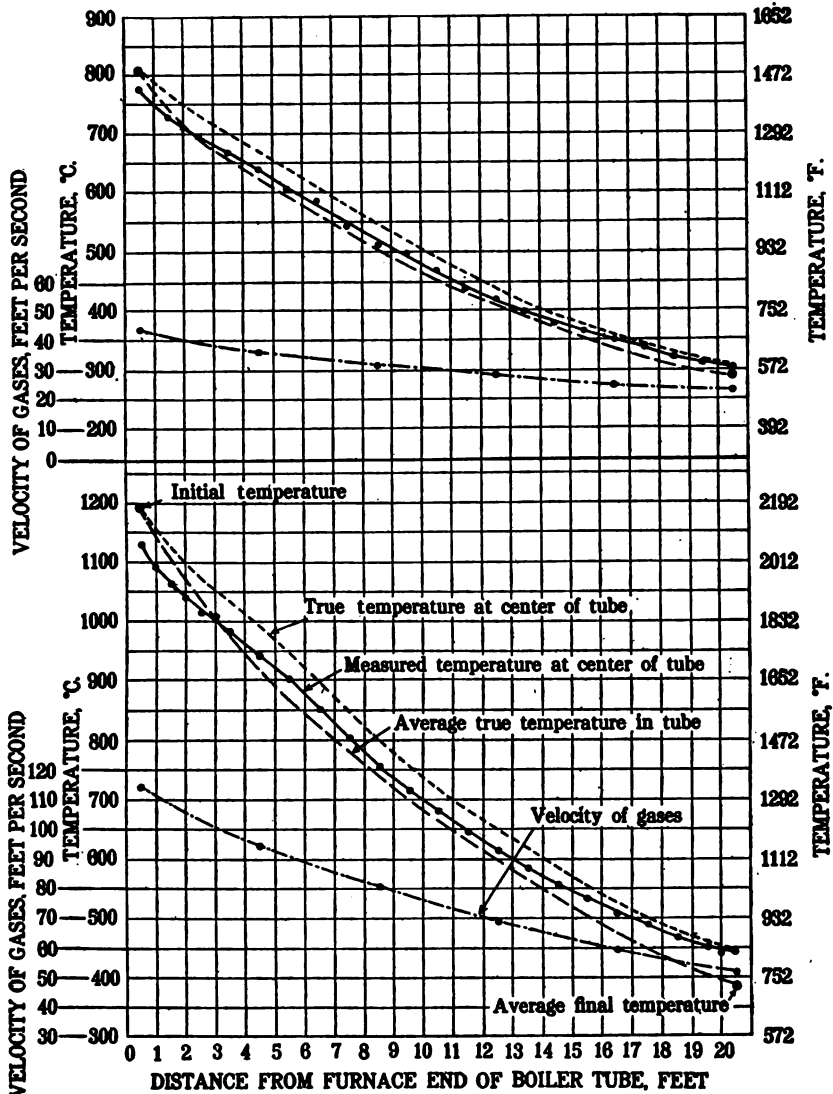


FIGURE 17.—Curves showing variations in temperature of gases flowing through a horizontal tubular boiler, having tubes 2½ inches in internal diameter, fired with natural gas. ———— measured temperature in center of tube. - - - - - true temperature in center of tube. ———— true average temperature of gases in tube. ———— computed velocity of gases.

higher was due to the high radiation error of the thermocouple, caused by the high temperature difference between the thermocouple and the surfaces surrounding it, and also to the fact that the tem-

perature of the gases across the whole section was nearly uniform, making the average about the same as the temperature at the center. On the other hand, near the exit end the radiation error of the thermocouple was small because of the small temperature difference between the thermocouple and the surfaces surrounding it. In addition the indicated temperature of the gases was much higher at the center than at points nearer to the surface of the tube, so that the average was considerably below the temperature at the center. For these two reasons the average true temperature at the exit end was lower than the indicated temperature at the center of the cross section of the tube. The larger variation in temperature across the diameter of the tube nearer to the exit end is shown in figure 24 (p. 47). These features will be discussed more in detail in a forthcoming paper to be devoted to heat transmission in a fire-tube boiler. In the present paper only enough data is presented to make possible a comparison of the temperature drop of the gases as they flow through boilers of different types.

COMPARISON OF THE TEMPERATURE DROP OF GASES AS THEY FLOW THROUGH BOILERS OF DIFFERENT TYPES.

Comparison of figures 1, 3, 5, 7, 9, and 17 reveals the fact that by far the greater part of the temperature drop occurs in the first one-third of the gas path. This drop is much greater in all the water-tube type of boilers than it is in the fire-tube boiler; and seems to be somewhat greater in the cross-flow type than in the parallel-flow type of boilers. The steeper temperature drop in the first one-third of the gas path of the water-tube types of boilers as compared with the fire-tube boilers is very likely due to more violent mixing of the gases as they flow among the tubes, the flow at right angles to the tubes probably causing better mixing than the parallel flow.

It should be borne in mind that none of the boilers used in these investigations are purely cross-flow or parallel-flow type, inasmuch as in both types successive parts of the gas path are cross flow and parallel flow, as can be easily seen by following the paths indicated in figures 2, 4, 6, 8 and 10. However, the five boilers may be grouped in two classes in which one or the other type of flow predominates. Thus in the Babcock & Wilcox boiler the cross-flow parts of the paths are longer than the parts with the parallel flow; whereas in the Heine and in the Parker boiler the parts with the parallel flow predominate. The curves for the temperature drop through the water-tube boilers have a very pronounced curvature about one-third of the distance from the point where the gases enter among the tubes. The fire-tube boiler gives a much smoother and straighter curve, especially when the initial temperature of the gases is low, then the

curve almost approaches a straight line. This great difference between the shape of the curves for the two types of boilers indicates that the process of heat transmission is much more complicated in the water-tube than it is in the fire-tube boilers.

DISCUSSION OF RADIATION ERROR.

CAUSES OF RADIATION IN MEASURING TEMPERATURES OF GASES IN BOILER SETTINGS.

When it is desired to measure the temperature of water or any other liquid, a mercury thermometer is immersed in the liquid and the instrument in time acquires the same temperature as the liquid. If the liquid is hot, heat flows from it into the instrument, and the temperature of the latter rises; if the liquid is cold, heat flows from the instrument into the liquid and the temperature indicated by the instrument falls. When the temperature of the liquid and that of the instrument are equalized, the transfer of heat ceases. The instrument loses no heat except a negligible amount by conduction through the stem to the part not immersed in the liquid, and therefore indicates the true temperature of the liquid.

In measuring the temperature of gases inside of a boiler setting, different conditions are encountered than in measuring liquids. If the same methods are followed as in measuring temperatures of liquid, serious errors may be introduced. The presence of the cold heat-absorbing surfaces of the boiler and the fact that gases when clean are permeable to radiation make equalization of the temperature of the gases and that of the instrument impossible. The heat constantly flows by convection from the gases to the instrument, and from the instrument by radiation to the cold surfaces of the boiler. Thereby a difference between the temperature of the gases and that of the instrument is maintained. The readings obtained under such conditions represent the temperatures of the instrument—the mercury bulb or the hot junction of a thermocouple, as the case may be—and not the temperature of the gases, just as the tubes of a boiler are not at the temperature of the gases, although in direct contact with them. The boiler tube receives heat from the gases by convection and gives it off by conduction and convection to the water. Inasmuch as there must be a drop in temperature for heat to pass from the gases to the tube and also from the tube to the water, the temperature of the tube is between that of the gases and that of the boiler water. In like manner heat is imparted to the thermometer bulb or to the hot junction of the thermocouple by convection from the hot gases, and is radiated from the thermometer or thermocouple to the boiler tube, which is always at a temperature considerably

lower than that of the gases. There is a temperature drop from the hot gases to the instrument and another temperature drop from the instrument to the surface of the boiler tube. Therefore, the temperature of the thermometer or the thermocouple is not the same as that of the gases, but is somewhere between the temperature of the gases and that of the boiler tube. In other words, the temperature of the measuring instrument is always lower than that of the moving gases.

Where the gases flow through a passage surrounded by surfaces hotter than the gases, the flow of heat is reversed and the temperature of the measuring instrument is higher than that of the gases. Such conditions occur in heat-regenerating apparatus in metallurgical furnaces, but are seldom met in steam-boiler practice.

How near the temperature of the measuring instrument is to the temperature of the gases in an ordinary boiler setting depends on the relative resistances to the flow of heat from the gas to the instrument and from the instrument to the boiler tube. When the temperature indicated by the instrument is constant, the amount of heat imparted to it by the gases is equal to the amount radiated from it to the tube. If the resistance to the flow of heat from the gases to the instrument is very small as compared to the resistance from the instrument to the boiler tube, the temperature drop is also very small and the temperature indicated by the instrument is very near that of the gases. If, however, the first-named resistance is high as compared with the second one, the temperature drop from the gases to the instrument is high, and the temperature of the instrument will be near that of the boiler tube.

FACTORS AFFECTING HEAT EXCHANGE.

Now, what determines these resistances, or the ease with which heat flows to the instrument and from it? It has been stated that heat is imparted to the instrument by convection, and flows from it by radiation. It can be shown that the amount of heat imparted to the instrument by convection is approximately proportional to (a) the difference between the temperature of the moving gases and that of the surface of the instrument receiving the heat, (b) the velocity of the moving gases, (c) the density of the gas, and (d) the extent of the surface receiving the heat. The amount of heat that is radiated from the instrument is approximately proportional to (a) the difference between the fourth powers of the absolute temperature of the instrument and of the boiler tubes, and (b) the extent of radiating surface of the instrument. The two quantities of heat can be expressed by two algebraic expressions, as follows:

$$(1) \quad H_c = C(T - T_1)vgS$$

$$(2) \quad H_r = K[(T_1)^4 - (T_2)^4]S_1$$

H_c = heat imparted to instrument by convection,

H_r = heat radiated from instrument,

T = temperature of moving gases,

T_1 = temperature of couple,

T_2 = temperature of boiler tubes,

v = velocity of moving gases,

ρ = density of gases,

S = extent of that part of the surface of the instrument receiving heat by convection,

S_1 = extent of that part of the surface of the instrument radiating heat,

C and K = constants.

In equation 1 the velocity of the gases is proportional to their volume. The volume is proportional to the weight of gases passing a given cross section per unit of time, and also directly proportional to their absolute temperature. The density of the gases is inversely proportional to their absolute temperature. Therefore, in equation 1 the product vg equals Cw , where w is the weight of gases, and C is a constant. Equation 1 then takes the form $H_c = C(T - T_1)wS$.

The temperature of the instrument is read when it is nearly constant; that is, when the quantity of heat the instrument receives from the hot gases is equal to the quantity that it radiates to the surrounding cooler surfaces, or when $H_c = H_r$, or,

$$(3) \quad C(T - T_1)wS = K[T_1^4 - T_2^4]S_1$$

In equation 3 the difference $T - T_1$ is the radiation error; that is, it shows how much lower the temperature of the measuring instrument is than the temperature of the gases. By studying this equation the effect of the various factors on the magnitude of the radiation error can be predicted. Thus if T , the temperature of gases, is raised the value of the temperature factor $T - T_1$ on the left side of the equation becomes larger, and therefore the rate of heat impartation to the instrument by convection is increased. The rate of heat radiation from the instrument is not directly affected, so that more heat is received by the instrument than is given off, and therefore its temperature T_1 rises. The rise in T_1 increases the value of the temperature factor $(T_1)^4 - (T_2)^4$ in the right side of the equation, thereby increasing the rate of heat radiation from the instrument. At the same time the rise of temperature of the instrument T_1 reduces the value of the temperature factor $T - T_1$ in the left side of the equation, thus reducing the rate of heat impartation to the instrument. The temperature of the instrument T_1 continues to rise until equilibrium is established and the values of the two sides of the equation are equal. However, owing to the fact that in the right side of the equation T_1 enters as the fourth power and in the left side only as the first power, the rise in T_1 is much smaller in proportion to the rise of T , the

temperature of the gases, when equilibrium is reached. This means that the radiation error is much larger when the temperature of the gases is high than when their temperature is low.

The weight of the gases, w , directly affects only the left side of the equation; that is, the amount of heat imparted to the instrument. If the weight of gases is increased the rate of heat impartation to the instrument is also increased. When more heat is put into the instrument than is radiated from it its temperature, T_1 , rises. This rise in T_1 increases the rate of heat radiation from the instrument and decreases the rate of heat impartation to it. The rise in T_1 continues until the two sides of the equation are equal. Therefore the higher the velocity of the gases the smaller is the temperature difference $T - T_1$ on the left side of the equation and the smaller the radiation error.

RELATION OF HEAT RADIATING AND RECEIVING SURFACES OF INSTRUMENT.

The extent of the surfaces S and S_1 is the most important factor in measuring temperatures of moving gases inside of a boiler setting. It is the only factor that can be controlled in the temperature measurements under any given conditions of boiler operation, the weight of the gases w then remaining constant.

The extent of the surface, S , receiving heat by convection is always greater than the radiating surface, S_1 . This fact follows from the nature of the modes of heat transmission to the instrument and from it. Convection delivers heat not to the surface of the metal or glass of the instrument, but to the gaseous film surrounding the solid surface. The thickness of this gas film is probably the same no matter what the diameter of the instrument, so that it can be said that the extent of the heat-receiving surface S is roughly proportional to the quantity $d + 2\delta$, where d is the diameter of the instrument and δ is the average thickness of the gas film.

To make this reasoning logical, it is necessary to state that the amount of heat imparted by convection is proportional to the difference between the temperature of the hot moving gas and that of the surface of the gas film. That is, if T_s is the average temperature of the surface of the gas film, the rate of heat convection is equal to $C(T - T_s)$, because in our consideration of the size of the instrument w the weight of gases remains constant and is embodied in C . But under these conditions $(T - T_s)$ is proportional to $(T - T_1)$ and therefore $C(T - T_1)$ can be used in place of $(T - T_s)$.

This proportion is evident, and can be shown in the following way. The same quantity of heat $C'(T - T_s)$, imparted to the gas film by convection, must be transmitted through the gas film by conduction

and may be expressed by the formula $C''(T_s - T_1)$, where C'' is a constant. We can therefore write the equation—

$$C'(T - T_s) = C''(T_s - T_1)$$

or

$$K(T - T_s) = (T_s - T_1).$$

By definition of temperatures

$$T - T_1 = (T - T_s) + (T_s - T_1) = (T - T_s) + K(T - T_s).$$

Therefore

$$(T - T_1) = C(T - T_s)$$

Inasmuch as the gases are permeable to radiation and when heated themselves radiate practically no heat, the extent of the heat-radiating surface of the instrument is the same as that of the metal or glass of the instrument. It can be said, therefore, that S_1 is proportional to the diameter d of the instrument. It is evident that when the diameter d decreases S_1 decreases faster than S , and therefore the amount of heat radiated from the instrument decreases faster than the heat imparted to it by convection. As a result of this unequal decrease the temperature of the instrument rises when its diameter decreases. This feature can be made clearer by the following specific example:

In the experiments reported in this bulletin two thermocouples were used to measure the temperature of the gases inside the boiler setting. One of these couples was about 0.500 inch in diameter and the other was 0.008 inch. If the thickness of the film is assumed to be 0.010 inch, the heat-receiving surface, S , of the large couple is

$$S \propto (0.500 + 0.02)$$

and the heat-radiating surface of the same couple is

$$S_1 \propto (0.500).$$

The heat-receiving surface of the small couple is

$$S \propto (0.008 + 0.02)$$

and the heat-radiating surface of the same couple is

$$S_1 \propto (0.008).$$

By stepping from the large couple to the small couple the heat received has been diminished by the quantity $\frac{0.520}{0.028} = 18.5$, whereas the heat given off has been reduced by the quantity $\frac{0.500}{0.008} = 62.5$.

The reduction of the surface controlling the heat given off is 3.4 times larger than the reduction in the surface controlling the heat received. As a result of these unequal reductions of surfaces, the

temperature difference between the instrument and the boiler tube ($T_1 - T_2$) must be increased and the difference between the temperature of the gas and that of the instrument decreased in order that the equality between the two heats is maintained, and consequently the temperature indicated by the smaller couple is much nearer to the temperature of the moving gases than that indicated by the large couple.

The unequal decrease in the heat-receiving and the heat-radiating surface when the diameter of the couple is decreased is illustrated in figure 18. It is strikingly apparent that in the upper diagram

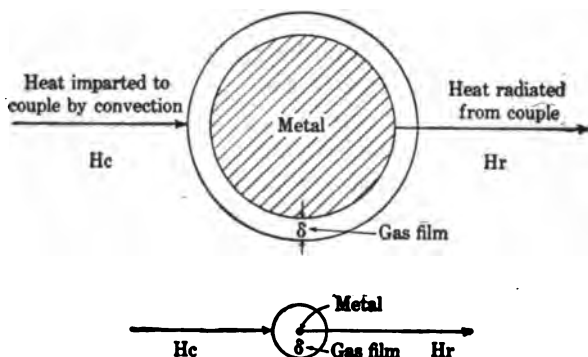


FIGURE 18.—Diagram showing that the surface radiating heat decreases faster than the surface receiving heat by convection, when the diameter of the instrument decreases. H_c , heat imparted by convection to couple. H_r , heat radiated from couple.

illustrating a cross section of a large couple, the ratio of the surface of gas film to the surface of the instrument is much smaller than it is in the lower diagram illustrating a cross section of a small couple.

EXPERIMENTAL DATA SHOWING RELATION BETWEEN SIZE OF THERMOCOUPLE AND RADIATION ERROR.

It has been shown in the preceding pages that in measuring the temperature of the gases in a boiler setting the radiation error was much smaller with the small couples than with the large ones. Therefore it is safe to assume that with any given conditions of exposure of the couples the radiation error has a definite relation to the size of the couple. To establish such relation for the conditions similar to those met with in the temperature measurements described in this bulletin two sets of four couples of different sizes were made and their temperature indications when placed in a boiler setting were studied. One of these sets was of platinum and platinum-rhodium and the other of copper and constantan. The diameters of a copper-constantan couples were 0.550, 0.250, 0.024, and 0.008 inch, and those of the platinum couples were 0.450, 0.310, 0.024, and 0.008

inch. Of these couples the two small ones of each set were made similar to the small couples of the respective sets shown in figure 11, and the construction of the two large couples of each set was similar to that of the large couples shown in the same figure. The four couples of each set were clamped together in such a way that the hot junctions were about 1 inch apart; the two large couples were on the outside and the two small ones on the inside of the group. The platinum and platinum-rhodium set was placed in position *A* of the double-pass Heine boiler, where it was partly exposed to the boiler tubes. The copper-constantan set was placed in the hood, or position *F*, of the same boiler. At the beginning of the experiment the 0.024-inch couple of this set broke, so that readings with only three couples were obtained. Readings of all these couples were taken in rapid succession, and while the readings were being taken the furnace conditions were kept as uniform as possible. Smokeless Pocahontas coal was used to avoid as much as possible the deposition of soot and other solids on the couples.

RELATION BETWEEN DIAMETER OF COUPLE AND INDICATED TEMPERATURE.

The results of four series of readings obtained with these couples are plotted in figure 19. The two sets of curves *A* and *B* at the top of the figure show two series of readings taken with the platinum and platinum-rhodium couples, and the sets of curves *C* and *D* at the bottom of the figure show two series of readings taken with the copper-constantan couples. In each group the order of the curves is according to the size of the couple, the lowest curve representing the readings obtained with the largest couple and the highest curve the readings taken with the smallest couple.

Plotting the diameter of the couples as abscissas and the readings of the couples as ordinates gave the curves shown in figure 20. The highest curve *A* in this figure contains four points representing the averages of three series of readings obtained with the four different sizes of couples when placed in position *A* in the double-pass Heine boiler (see fig. 6). In this position the couples were exposed largely to the walls and the bottom of the furnace, partly to the tile roof, and to a small extent to the tubes of the boiler, so that the exposure to the hot brick surfaces greatly predominates. This brickwork was heated to dull red or to about 700° C.

The curve *B* contains four single readings taken under the same conditions of exposure as *A*, but with somewhat lower temperature of the surrounding surfaces and of the gases.

The curve *M* contains two average points taken with a twin couple placed in position *B* in the Babcock & Wilcox boiler shown in figure 2. In this position the couples were exposed almost entirely to the

surfaces of the boiler tubes, which were at a temperature of about 275°C .

The curve *N* passes through three points, which are the averages of several readings taken with three sizes of couples placed in the uptake of the double-pass Heine boiler in the position indicated by *F* in figure 6. At this place the couples were partly exposed to the surfaces of the boiler, the surfaces of the brick uptake, and the sur-

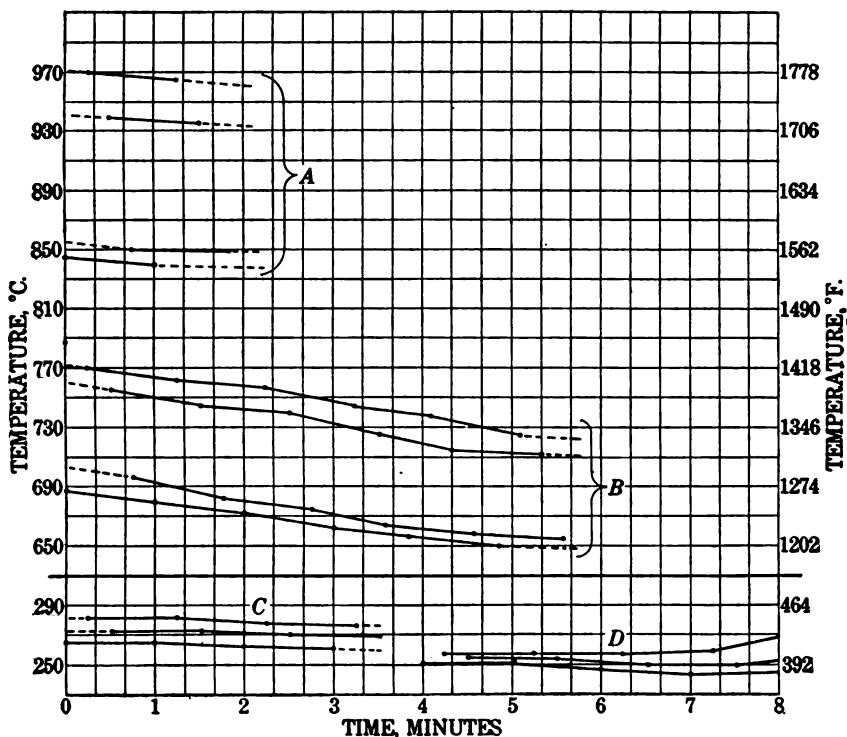


FIGURE 19.—Curves showing temperature indicated by couples of different sizes when placed in same position in a boiler setting. Series *A* and *B* were taken with four platinum and platinum-rhodium couples, 0.008, 0.024, 0.310, and 0.450 inch in diameter placed in position *A*, figure 6. Series *C* and *D* were taken with three copper-constantan couples, 0.008, 0.250, and 0.550 inch in diameter, placed in position *F*, figure 6. In each group the order of the curves is according to the size of the couple, the smallest couple reading the highest and the largest one the lowest.

faces of the sheet-metal hood. The average temperature of these surfaces was probably close to 210°C .

Strictly speaking, the readings of the two largest platinum couples are not comparable with those of the two smallest couples, because the radiating surface of the large couples was fused silica, which has a larger coefficient of emissivity than the platinum of the two small exposed couples. But the effect of the difference of emissivity of the two materials is comparatively small and can be neglected so far as the purpose of this bulletin is concerned.

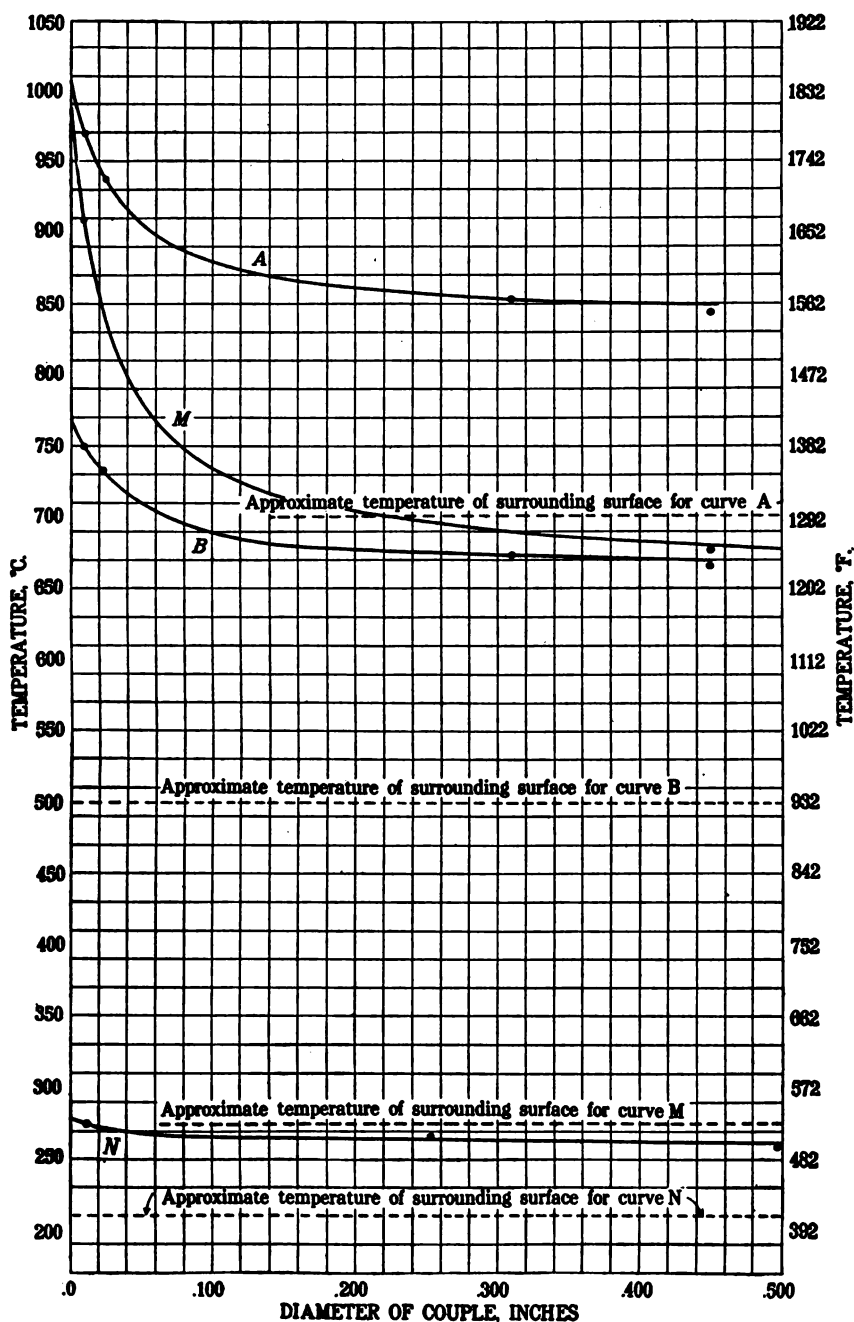


FIGURE 20.—Curves showing relation between diameter of couple and temperature indicated by couple, when measuring temperature of hot gases surrounded by cooler surfaces. Temperature for zero diameter of couple is true temperature of gases.

The curves in figure 20 show that as the diameter of the couple decreases the radiation error decreases very slowly at first, and then rapidly as the couple is reduced through the very small sizes to zero diameter. The correct temperature of hot gases flowing through a passage surrounded by colder surfaces can be obtained only with a couple of zero diameter, the construction of which is a physical impossibility. Therefore under the given conditions the correct temperature of the gases can be closely approximated by the use of curves such as are shown in figure 20. The smaller the couple the nearer will it indicate the true temperature of the gases.

The relation between the radiation error and the diameter of the couple is not a simple one because of the many factors entering in, such as the temperature of the gases, the temperature of the surrounding colder surfaces, and the amount of exposure to these surfaces, but can be approximated by using equation 3 (see p. 35). On account of the temperature variable being expressed as the fourth power, the equation is rather cumbersome, and its solution can be made much easier by making T_2 equal to 1 and expressing the other temperatures as ratios of T_2 , remembering what this provisional unit is and changing the final results into the standard units. Such substitution of units eliminates one fourth-power factor and reduces the value of the constant $\frac{C}{K}$ to a convenient figure. Substituting arbitrary temperature units by this method, the equation of the two curves A and B takes the form,

$$D[(T_1)^4 - (T_2)^4] = 3.9(D + 0.08)(T - T_1).$$

For the curves M and N , which represent conditions of exposure and velocities of gases different from those of curves A and B , the values of the constant $\frac{C}{K}$ are 12 and 10.8, respectively.

According to these equations the thickness of the gas film about the couple is 0.04 inch or about 1 millimeter. This value may seem too large, but with smaller values the part of the curve near the zero diameter end would rise more rapidly than the observed points permit.

It is also probable that the thickness of the gas film varies with the temperature and somewhat with the diameter. It would seem that as the diameter of the couple becomes smaller its temperature rises, and because of this rise in temperature and the reduction in diameter the thickness of the film decreases. However, if such a decreasing value for the thickness of the gas film is substituted, the left end of the curve rises too rapidly and misses the points representing temperatures obtained with the small couples.

Data at hand are not complete enough to justify a more detailed theoretical investigation of the thickness of the film and other constants in the equation. The discussion given in the preceding paragraphs has been presented as a suggestion of a possible method by which the radiation error problem can be solved. For the satisfactory solution of the problem a far more complete set of observations is necessary. Such data will have to be obtained in a specially designed apparatus where all the conditions can be controlled; a boiler setting is not in that class of apparatus. The data presented in this paper show beyond doubt that when the temperature of moving gases surrounded by colder surfaces is measured by couples of different diameters, the temperature indicated by the couples forms a curve which has a very steep bend as the diameter of the couple approaches zero. The smaller the couple the nearer does it indicate the true temperature of the gases.

EFFECT OF TEMPERATURE OF GASES ON RADIATION ERROR.

From the discussion of equation 3 (see page 35) and the curves of figure 20, it is apparent that the higher the temperature of the gases in any given gas passage, the higher is the radiation error, and the greater will be the difference between the temperature readings of two couples having different diameters. This feature is shown more clearly by the curves in figure 21, which were compiled from the temperature measurements plotted in figures 1, 3, 5, 7, and 9. In this figure the differences between the temperatures indicated by the small and the large couple are plotted as ordinates and the temperature indicated by the small couple as abscissas.

Figure 21 shows the temperature differences for the Babcock & Wilcox, the Parker, the Stirling, and the two Heine boilers. The readings for each of the five boilers are indicated by differently shaped points, and the readings of each twin couple are represented by a group of points inclosed by an irregular line, the position of the couple being designated as shown in figures 2, 4, 6, 8, and 10. All the points fall close to some line that passes through the point representing zero ° C. and 32° F., and rises as the temperature rises. These lines show a slight curvature with the convex side toward the abscissas, indicating that the difference increases faster than in direct proportion to the temperatures.

EFFECTS OF CONDITIONS OF EXPOSURE OF COUPLE ON RADIATION ERROR.

Figure 21 shows also that the radiation error is different for different conditions of exposure of the couples. Thus all of the twin couples placed among the boiler tubes of the Babcock & Wilcox boiler

had the same conditions of exposure, and therefore the points representing their readings fall along one smooth curve. The twin couple *A*, however, was partly exposed to the boiler tubes and partly to the furnace walls, which were hotter than the tubes, and therefore its radiation error was less. This is shown clearly by the fact that the points representing readings of this twin couple fall on a curve con-

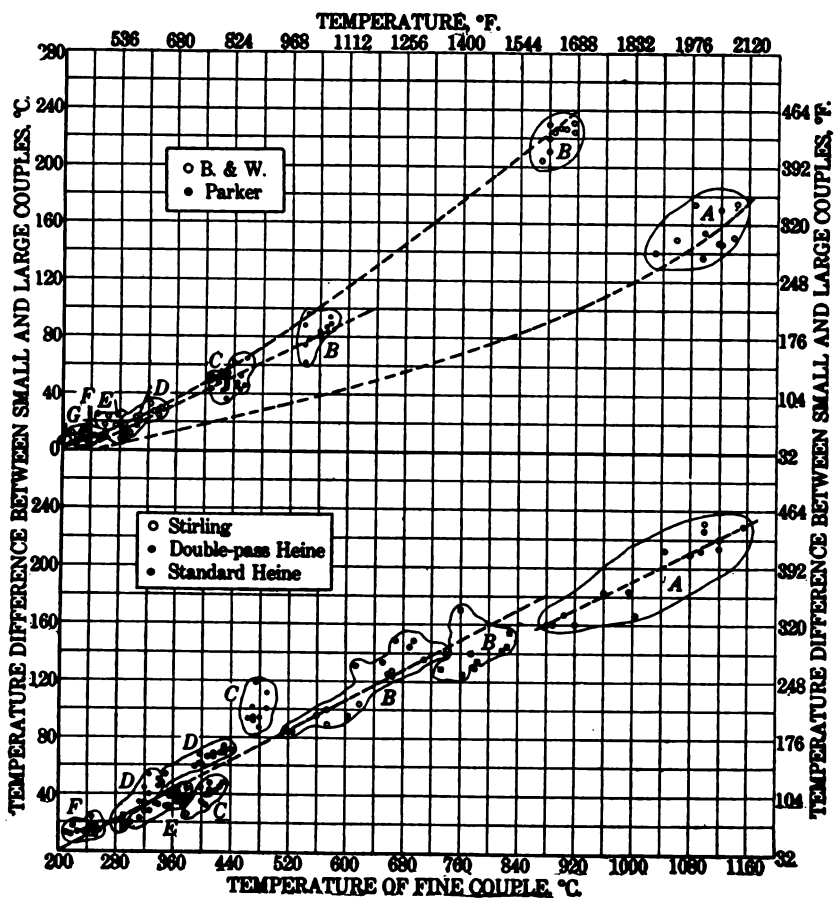


FIGURE 21.—Curves showing effect of temperature of gases on radiation error. Results of temperature measurements in five types of boilers. Measurements by each twin couple are represented by a group of points inclosed within a thin border line and are designated by the position of the couple.

siderably below the curves for the other couples. Thus, for example, when the small couple of the twin *B* read $900^{\circ}\text{C}.$, the large couple read $230^{\circ}\text{C}.$ lower; when the small couple of the twin *A* read $1,100^{\circ}\text{C}.$, the large couple read only about $160^{\circ}\text{C}.$ lower than the small one. This feature has been discussed in connection with equation 3 on page 35.

CONCEPTION OF THE GAS FILM NEXT TO SURFACES OF SOLIDS.

The conception of the reality of the gas film around a solid is a fundamental factor in the explanation of the fact that the radiation error is smaller with small couples than it is with large ones. The layer or film of gas at the surface of a solid body is not a mathematical factor but is a physical reality, although rather difficult to define exactly. It is perhaps easier to describe such a film than to define it. The following is the authors' conception of the film:

Figure 22 will help in making this conception clear. When a solid body *A* is placed in a stream of moving gas, a very thin layer

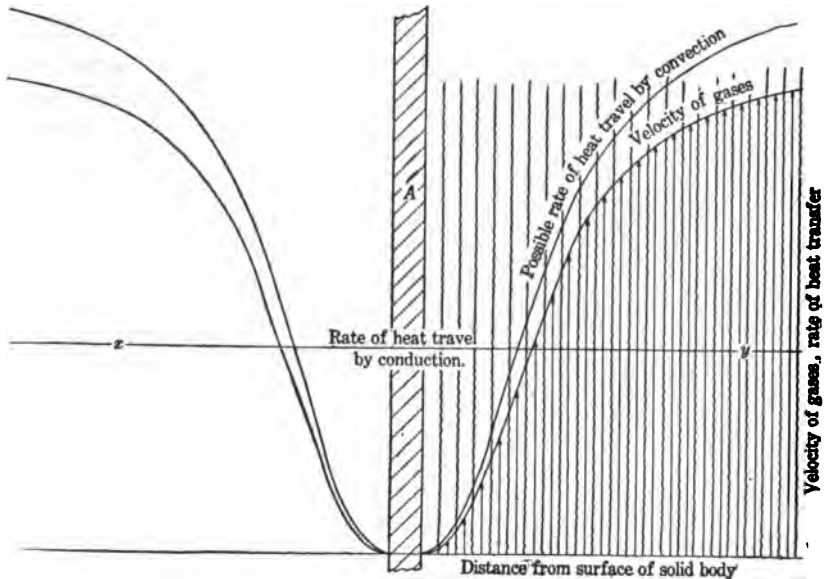


FIGURE 22.—Diagram showing the relative velocity of infinitesimal layers in a film of gas next to a solid surface. Layers are represented by spaces between wavy lines; velocities of layers by length of arrows. Curve having ordinates proportional to velocity represents possible rate of travel of heat by convection; horizontal line *XY* represents possible rate by conduction. A plane parallel to *A* and passing through point of intersection of the two curves may be considered the surface of the gas film.

of gas adheres to its surface and has no motion. This layer of immovable gas is perhaps only two or three gas molecules thick, and is probably similar to the layer of water adhering to the surface of a solid when it is wetted by dipping in water. Next this layer of immovable gas is another layer which moves, but its velocity is very small compared to the average velocity of the gas stream. Farther away are successive layers, each of which has a velocity somewhat greater than the preceding one, until the velocity of the main body of the stream of gases is reached. The rate of increase in velocity of the successive layers is at first small, but becomes greater and

greater until the layers about one-eighth of an inch from the solid body are reached; then the rate again becomes smaller as the layers having maximum velocity are approached. In figure 22 the successive layers of gas are represented highly magnified by the spaces between the wavy lines, and the magnitude of their motion is indicated by the length of the arrows. Thin, wavy lines are used to indicate that the successive layers are not sharply separated but merge into one another. The particles of gas, in fact, pass from one

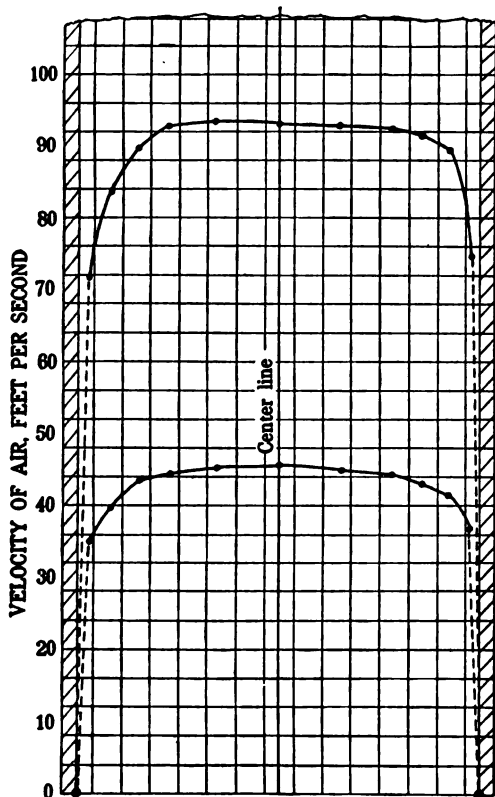


FIGURE 23.—Diagram showing variation in velocity of air current across diameter of an 8-inch pipe as actually measured with a small Pitot tube.

layer into another by the rolling motion of small eddy currents. The spaces representing the layers are shown very wide in order to make the diagram clear. In reality the thickness of each layer is infinitesimal, so that the entire width of the diagram on one side of the solid *A* represents the conditions in a space of about one-eighth of an inch thick, measured from the surface of the body. The smooth curve connecting the heads of the arrows indicates the variation in the velocity of the gases within this small space. The curve is shown to have a double curvature, being convex near the surface of the solid body, and concave farther away near the layers having the average velocity of gas stream. The curvature near the surface of the solid extends through only a very short distance from the surface, and is practically impossible to show experimentally.

The great change of velocity within a space of one-eighth of an inch of the surface of a solid is represented in figure 23, which shows the velocity of an air current at different points in the cross section of an 8-inch pipe, as actually measured with a small Pitot tube. Two sets of measurements of two different rates of flow are

given. With the higher rate of flow, the velocity drop from the center of the pipe to one-eighth of an inch from the surface of the pipe is 22 feet per second. The drop within a $\frac{1}{8}$ -inch layer at the surface of the pipe is 71 feet. Drops of similar proportions were shown with the lower rate of flow.

When hot gases flow through a boiler tube the variation of temperature of the gases across a section of the tube is similar to the variation of velocity. This fact is shown in figure 24, which gives two sets of temperature measurements across a vertical diameter in a tube of a horizontal tubular boiler. The tube was $2\frac{1}{4}$ inches in inside diameter and 20 feet long. The cross section at which the higher temperature was measured was 1 foot and that at which the lower temperature was measured was 9 feet from the furnace end of the tube. The temperatures were obtained with an exposed platinum and platinum-rhodium couple 0.012 inch in diameter. These two temperature curves indicate that by far the

greater part of the temperature drop occurs within one-eighth of an inch distance from the walls of the tube, where the velocity drop occurs. The largest temperature drop is in the layer of gases next to the surface of the solid, where there is no motion at all or only a comparatively small one. Farther toward the center of the tube where the velocity is high, the temperature drop is small. Inasmuch as the temperature drop along a path of heat travel to a great extent indicates the resistance flow of heat these layers of inert or

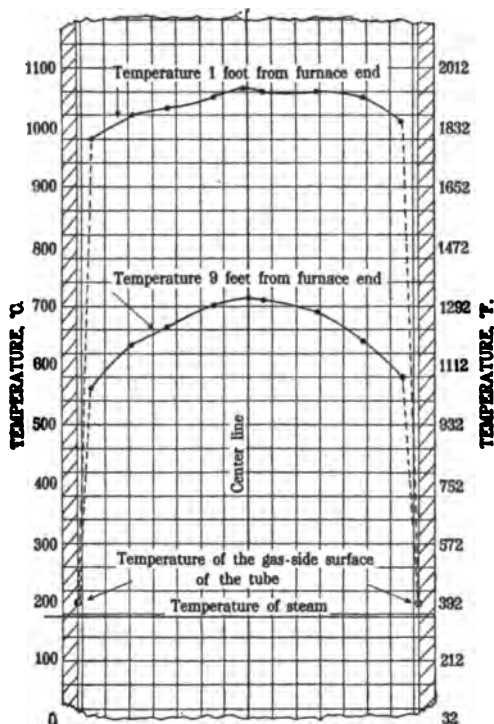


FIG. 24.—Diagram showing variations in temperature of gases across a boiler tube $2\frac{1}{4}$ inches in internal diameter. Temperatures were measured with an exposed platinum couple at 9 points on a vertical diameter. Upper curve represents temperature 1 foot from furnace end, average velocity of gases 108 feet per second; lower curve represents temperature 9 feet from furnace end, average velocity of gases 78 feet per second. Compare these temperature curves with the velocity curves of figure 23.

slow-moving gas present the highest resistance to the passage of heat, and the cause of the high resistance is obviously the lack of motion. With a given quantity of heat to transmit to the boiler tube, there must either be high velocity or high temperature drop along the path of heat travel; when the velocity decreases the temperature drop must increase in about the same proportion. In other words, there must be either a high velocity of the gases to transmit the heat by convection, or a large temperature drop to transmit it by conduction.

It has been sufficiently proved that the rate of heat travel through gas by convection is very nearly proportional to the velocity of the gas; and also that within reasonable limits of temperature the rate of heat travel by conduction is nearly constant. Therefore a curve such as the curving line in figure 22 can be drawn, its ordinates being made so proportional to the velocities that they represent the rate of heat travel by convection. The rate of heat travel by conduction, being constant, can be represented by a horizontal line, such as $x y$ in the figure. Above the point of intersection of the two curves, convection is the predominant mode of heat travel, whereas below the intersection point conduction predominates. The layers of gas near the surface of the solid body, where conduction predominates, are considered by the authors as the gas film and are represented in figure 18 by δ .

MEASURING THE TEMPERATURE OF FLUE GASES.

The steam-boiler operator frequently has need of determining accurately the temperature of the gases leaving the boiler. He may be confronted with the question of what is a good way of measuring flue-gas temperatures.

INSTRUMENTS USED.

Two types of instruments are in general use for measuring the temperature of flue gases—mercury thermometers and thermocouples. The mercury thermometers specially designed for this purpose are about 3 feet long and have a temperature range up to 1,000° F., and are usually placed in a protecting steel tube $\frac{1}{2}$ to $\frac{3}{4}$ of an inch in diameter. Unprotected thermometers about 18 inches long and of somewhat smaller temperature range are also used. The advantages of using thermometers are that the temperature can be read directly, and their low first cost. The chief disadvantages are that they have a large radiation error and, owing to their limited length, can not be placed at the most favorable point in the stream of gases, which introduces another considerable chance for error. Another unfavorable

feature is that frequently they have to be placed at an inaccessible part of the uptake or flue, so that reading is inconvenient. Breakage and destruction from flames in the flue adds considerably to the cost of using them.

The thermocouples used in measuring flue-gas temperatures are made of either platinum and platinum-rhodium or of different kinds of base metals. Among the base metals the ones most frequently used are the Hoskin couple, made of nickel and nickel-chrome alloy, iron and constantan, and copper and constantan. Couples of various forms made of these metals can be bought in the market ready for use. Each of these couples has its advantages and disadvantages. The platinum couple has the advantage that the metal does not contaminate easily and, therefore, does not require recalibration, even with long usage. Its disadvantage in measuring flue-gas temperatures is that it has a low electromotive force, necessitating the use of a delicate galvanometer to indicate the temperature. The high cost of the couple, and of the galvanometer, is also a serious drawback to its use. The base-metal thermocouples have an electromotive force about four times that of the platinum couple and, therefore, small changes in temperature are easily measured with greater accuracy. They are more easily contaminated, and for that reason require more frequent testing. However, their first cost is so low that they can be frequently renewed without making their use expensive. The necessity of using an indicating instrument and its inherent weaknesses are a serious drawback in the use of all couples, whether of platinum or of base metal.

The galvanometer, which is the instrument most frequently used with a couple to indicate the temperature, measures the potential drop across its binding posts and not the potential impressed by the couple. If the internal resistance of the galvanometer is very high as compared to the resistance of the couple and of the leads, the potential drop across the binding posts of the galvanometer is very near the potential impressed by the thermocouple. If, however, the internal resistance of the galvanometer is low and the resistance of the couple and its leads is high and variable a serious error is sure to enter into the temperature measurements. Therefore it is advisable to use a galvanometer with as high internal resistance as possible. High resistance galvanometers are necessarily delicate and therefore require careful handling when carried from place to place and must be carefully leveled and adjusted before readings are taken. Such galvanometers also cost considerably more than those having a low resistance.

A portable potentiometer, which obviates most of the objections to a galvanometer except the high first cost, measures the potential impressed by the couple no matter how long the leads are and how variable their resistance; it is accurate and does not easily get out of order. Also a potentiometer is compact and robust in construction; it can be easily carried around a steam plant and does not need careful leveling for accurate reading.

During more than 12 years of testing work in commercial plants, as well as with special experimental apparatus, the writers tried various combinations of the instruments mentioned in the preceding paragraphs. They obtained the most satisfactory results with the copper-constantan thermocouple used with a portable potentiometer. Therefore detailed directions are given herein for using this combination in measuring flue-gas temperatures.

MAKING A COPPER-CONSTANTAN THERMOCOUPLE.

PURCHASING THE ELEMENTS.

Owing to the possibility of a couple being contaminated and the low cost of the copper-constantan thermocouple elements, it is advisable to buy the two kinds of wire in lots of several hundred feet and make couples of suitable length as they are needed. Whenever there is a suspicion that a part of the couple is contaminated this part can be cut off, or an entirely new couple made. Renewal of the couple is justified by the low cost. Five dollars will buy about 1,000 feet of each wire of No. 22 (B. & S. gage). When bought from a reliable maker any one roll of the wire is of very uniform composition, so that for practical purposes one calibration can be depended on for all of the wire in the roll. The writers, in testing the wire they use, found that calibrations of thermocouples made from various parts of a given roll checked very closely. No. 22 (B. & S. gage) wire is about 0.024 inch in diameter and a couple made from it has sufficient mechanical strength, also the wire is small enough so that the radiation error when the couple is inserted in the uptake is small. When buying the wires it should be specified that they are to be used for thermocouples, giving the thermoelectric relation about as shown by the curve in figure 28. This curve has been obtained by repeated calibration of couples made from the same rolls of wires in the physical laboratory of the Bureau of Mines.

MAKING THE HOT JUNCTION.

The hot junction can be made by welding the ends of the two wires together in a gas blowpipe or a gasoline blowtorch, borax

being used as a flux. It is rather difficult to bring the wires to welding temperature with an ordinary Bunsen gas burner. The writers obtained very good results with a gasoline blowtorch, which is available to practically all steam-plant operators. The following procedure will give good results:

Cut off the desired length of each wire and roll the two wires in separate coils 2 to 3 inches in diameter, leaving about 4 inches of each wire uncoiled. Get the blowtorch burning so that it gives a steady hot flame. Heat the free ends of the two coils to a red heat and quickly dip them while hot into powdered borax. The borax will adhere to the wires and form a coating which protects them from oxidation. Stand close to the torch with the flame blowing directly away; then, holding one of the coils in each hand, insert the borax-coated ends of the wires into the flame about 1 inch from the nozzle of the torch.

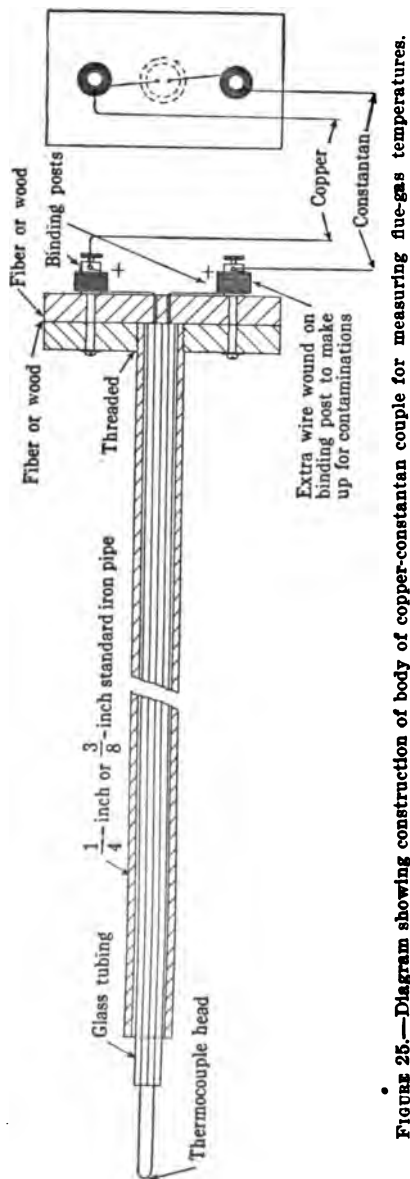
The elbows should be held against the body to give steadiness and the ends of the wires should be placed in the upper or lower edge of the cross section of the flame. Holding the wires near the edge of the flame insures rapid heating of a short length of the wire, the center of the flame not being as hot as the edges. The copper wire comes to melting point first. When both of the wires are at the point of fusion press the two ends together, then, holding the arms rigid, by slightly moving the body remove the junction from the flame and hold until cold. Holding the arms rigid prevents the junction being pulled apart while hot. A little practice may be necessary before a satisfactory joint is obtained. After the manipulation is once learned a good junction can be made at the first trial. However, if success does not come after repeated trials the welding can be accomplished by first fusing a very small piece of copper wire over the end of the constantan wire and then welding the copper wire to the coppered end of the constantan wire. After a good weld has been made the junction may be trimmed with a file so that it is of the same thickness as the rest of the wire.

MAKING THE BODY OF THE COUPLE.

After a satisfactory junction has been formed and is properly trimmed the wires of the couple are insulated with small glass tubes and placed in a $\frac{1}{4}$ -inch or $\frac{3}{8}$ -inch standard iron pipe of suitable length. To prevent the glass tubes from slipping out of the iron pipe, pieces of asbestos rope can be packed tightly around them at each end of the pipe. The hot-junction end of the couple can be made to project about 1 inch from the glass tubing, the latter being either flush with the end of the iron pipe or projecting about a half of an inch from it.

The cold end of the pipe can be fitted with a simple handle containing two binding posts to which are connected the free ends of the couple. The construction of this simple couple is shown in figure 25. An

iron pipe 5 or 6 feet long will answer all the requirements for measuring the temperature of flue gases in an ordinary boiler plant. The thermocouple wires may be cut 3 or 4 feet longer than the pipe and the extra length can be wound around the binding post. Whenever a piece of the hot end of the couple is cut off on account of contamination enough wire can be unwound from the binding posts to make up for the part cut off.



ARRANGEMENT OF THE COUPLE, ITS COLD JUNCTION, AND THE INDICATOR.

For rough measurements of flue-gas temperatures the indicating instrument can be connected with copper leads to the binding posts of the thermocouple. The cold junction of the couple is formed in the binding post where the copper lead joins the constantan element of the couple. The approximate temperature of the cold junction can be obtained by hanging a low-reading thermometer either on the binding post or near it so that the thermometer indicates nearly the temperature of the binding post. This temperature must be taken into consideration when figuring the temperature indicated by the

couple. This type of cold junction is simple, and for that reason it is frequently used in couples for measuring the temperature of flue gases. It has the drawback that its temperature can not be de-

terminated accurately and that the observer must climb on top of the boiler to read it.

The temperature of a water-bath cold junction attached to the couple as shown in figure 11 can be obtained quite accurately, but its location is not convenient for reading in everyday boiler-room work.

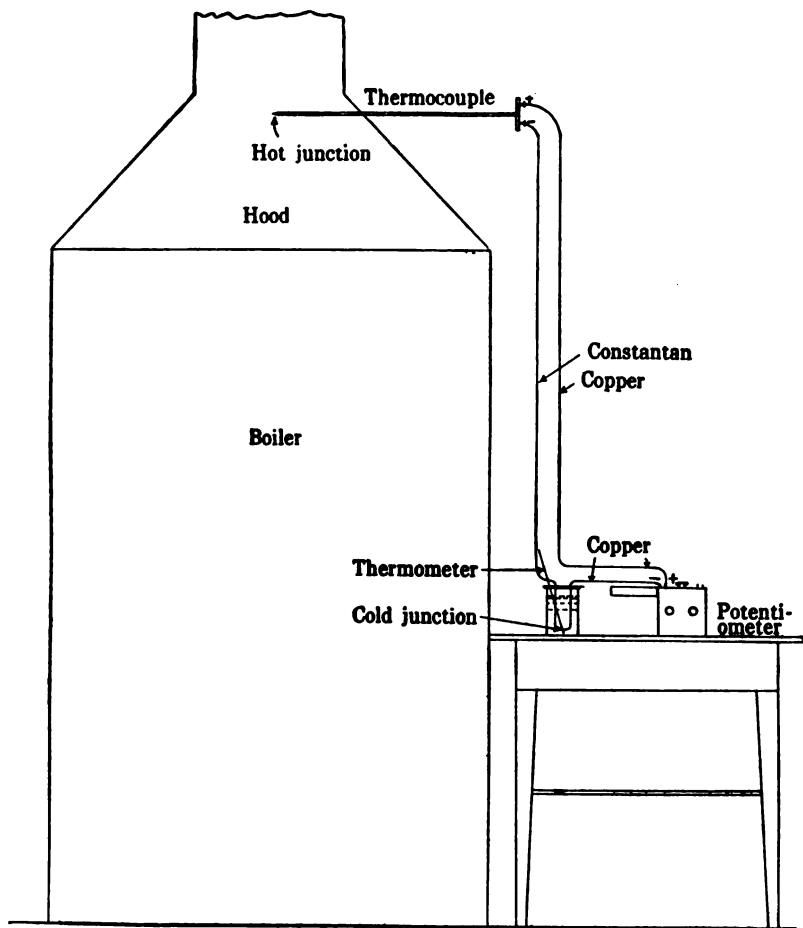


FIGURE 26.—Diagram showing arrangement of thermocouple, its cold junction, and the indicating instrument, when measuring the temperature of flue gases.

Perhaps the most satisfactory arrangement is the one in which the cold junction is placed with the indicating instrument on a table or a bench standing on the floor of the boiler room as shown in figure 26. An insulated copper wire is lead from the copper terminal of the couple directly to the positive binding post of the potentiometer. From the constantan terminal of the couple a constantan wire leads down to a water bath. To the lower end of the con-

stantan lead is soldered a piece of copper wire about 18 inches long, and the soldered junction is placed in the bend of a glass U tube which is submerged in a vessel of water as shown in figure 26. The free end of the piece of copper wire is connected to the negative binding post of the potentiometer. The cold junction of the couple is the soldered joint between the constantan wire and the short piece of copper wire placed in the bend of the U tube. Its temperature is determined by a thermometer inserted in the water bath, the temperature of the junction being the same as that of the water bath. This arrangement is very convenient to read and gives accurate results. The operator can read the potentiometer and the cold junction at the same time.

For most of the boiler-room testing work the water bath at the cold junction can be omitted and the constantan lead can be connected directly to the negative binding post of the potentiometer, the binding post of the instrument then being the cold junction. Its temperature can be fairly closely obtained by laying a thermometer over the instrument. The temperature of the binding post usually does not vary greatly, and the thermometer can be read from time to time when the potentiometer is read. This arrangement is a simple one and gives very satisfactory results.

MANIPULATION OF THE POTENTIOMETER.

An explanation of the principle of a potentiometer, and descriptions of the different types and makes of such instruments are omitted here because the reader can obtain such information in any textbook on laboratory physics and in the catalogues of different makers. The writers use in their work a small portable Leads & Northrup instrument mounted in a wooden box about 10 inches long by 6 inches wide by 6 inches high and weighing about 10 pounds. The manipulation of this instrument is herein described; other types and makes are manipulated in the same general way.

ADJUSTING THE INSTRUMENT.

Figure 27 gives the top view of the instrument connected for reading. An ordinary dry cell battery, connected as shown, is used, the standard cell inside the instrument being used only to standardize the dry cell. The first thing to be done after connecting the various parts of the apparatus is to see that the pointer of the galvanometer points to zero. If it does not, it must be adjusted by slightly turning the screw *D* in the direction that the pointer should be moved. This must be done very carefully, as a very slight motion of the screw changes the position of the pointer considerably.

After this adjustment has been made, the dry cell must be standardized. This is done by pressing the key *Sc* and turning the knob *R* one way or the other until the pointer of the galvanometer points approximately to zero. The final accurate adjustment is then done

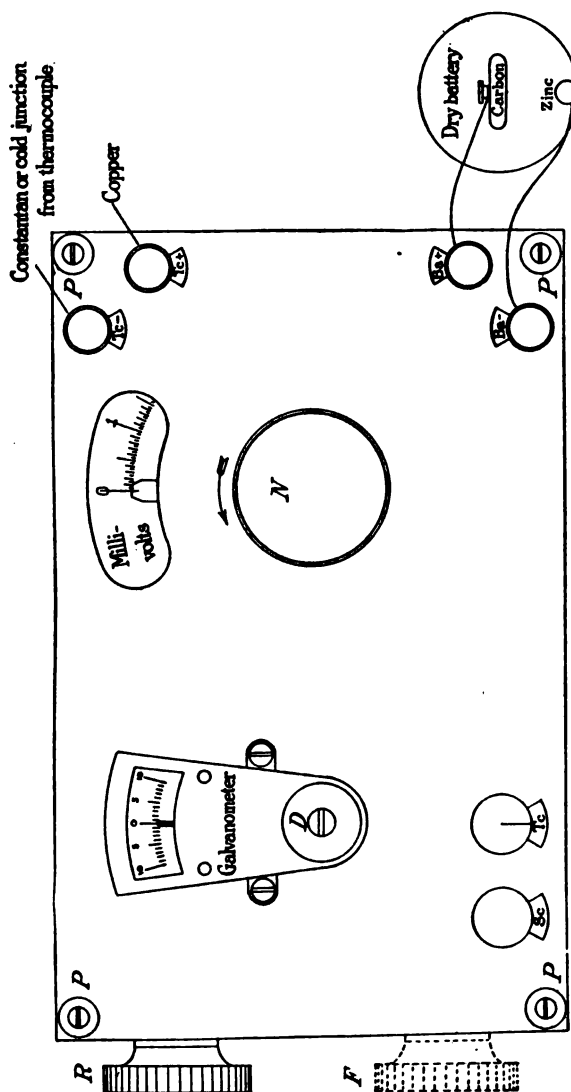


FIGURE 27.—Top view of a portable potentiometer. *D*, Screw for initial adjustment of galvanometer pointer; *R*, knob of coarse resistance for standardizing dry cell; *F*, knob of fine resistance for standardizing dry cell; *N*, knob for reading potential of couple; *Sc*, button to be pressed when standardizing dry cell; *Tc*, button to be pressed when reading potential of couple; *Ba*—, negative binding post of battery; *Ba*+, positive binding post of battery.

by turning the knob *F*, which requires considerable motion to move the pointer through a very small angle. When the pointer is properly adjusted and the dry cell standardized, the pointer should have no perceptible motion when the key *Sc* is alternately pressed and

released, and should stand at the zero point of the small scale of the galvanometer. The instrument is then ready for temperature readings. As the voltage of the dry cell changes somewhat with constant use, the adjustment should be frequently checked by pressing the key *Sc*. It may seem that the adjustment of the instrument and the standardization of the dry cell is a difficult and tedious task, but with a little experience the former takes about a minute, and the latter only a few seconds. Usually one adjustment a day of the pointer is sufficient unless the instrument is moved to different places, in which event the adjustment should be checked each time the instrument is moved.

READING THE TEMPERATURES.

Before reading the temperature the operator should make sure that the thermocouple leads are properly connected to the instrument. The constantan lead should be connected to the negative binding post and the copper lead to the positive post. To read the temperature the key *To* is depressed and the knob *N* turned in the direction indicated by the arrow until the galvanometer pointer is brought to the zero point of the small galvanometer scale. The reading is obtained from the scale turned with the knob *N*, and is given in millivolts.

The millivolt reading can be converted into temperature by means of a calibration curve such as shown in figure 28. The following is a general method which takes into account also the temperature of the cold junction:

Obtain the number of millivolts corresponding to the temperature of the cold junction; add this to the number of millivolts obtained from the potentiometer. The temperature corresponding to the sum is the temperature of the gases as measured by the couple.

EXAMPLES.

The following specific example illustrates the method: Suppose the reading of the potentiometer is 16.25 millivolts and the temperature of the cold junction is 20° C. Starting from the point representing 20° C., at the left of figure 28, follow the horizontal line until it intersects the curve; from this point follow the vertical line to the scale at the bottom and read the corresponding millivolts, which is 0.80. This, the cold junction correction, should be added to the number 16.25 read from the instrument, giving the sum 17.05 millivolts. On the scale at the bottom of the diagram estimate the position of the point 17.05, and from it follow an imaginary vertical line to the curve; from the intersection point of this imaginary line

and the curve follow an imaginary horizontal line to the centigrade scale at the left or the Fahrenheit at the right. The temperature is 340°C . or 644°F .

Another example is as follows: The temperature of the cold junction is 35°C ., and the potentiometer indicates 17.50 millivolts. The correction of the cold junction, corresponding to 35°C . as obtained from the curve, is 1.3 millivolts. Adding this to the reading

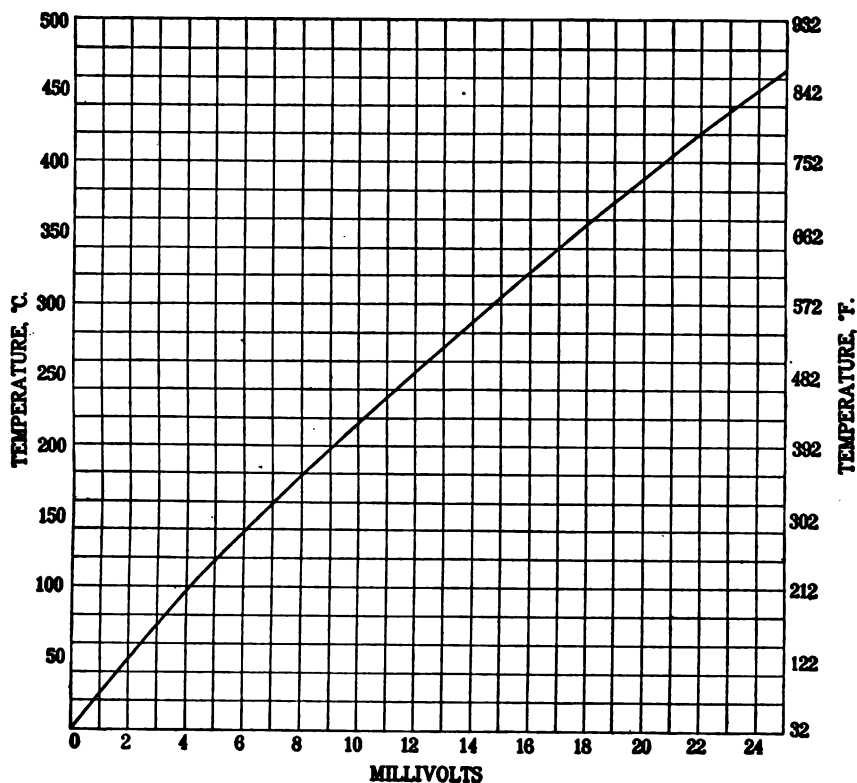


FIGURE 28.—Curve showing relation between millivolts and temperature for a copper-constantan couple.

of the potentiometer gives 1.3 plus 17.50 equals 18.8 millivolts. The temperature corresponding to this value is 370°C . or 698°F .

PLACING A THERMOCOUPLE FOR MEASURING FLUE-GAS TEMPERATURES.

In measuring the temperature of flue gases, the position of the thermocouple is very important. Although no specific directions can be given as to the exact point for placing the thermocouple, it can be said that in general it is best to insert the thermocouple into the hood

or uptake in such a way that the hot junction is in the center of the stream of gases and as far as possible from any cold surface. Before any definite position is selected the hot junction of the thermocouple should be moved to different points in the stream of gases and the difference in temperature noted. The couple can even be moved and inserted into different holes in the uptake or breeching. After this preliminary survey of the temperatures at different points the operator can decide for himself the best position for the couple. It is perhaps generally the best to place the couple where it gives the highest temperature, otherwise the results are apt to be affected by air filtering in or by radiation to some cold surface to which it is exposed. The radiation error, however, is far less in a couple constructed as directed on page 51 than it would be if a thermometer were used. It is highly improbable that the indicated temperature will be too high. An excellent example of a high radiation error when a large flue-gas thermometer was improperly placed is given by the tests made on a Stirling boiler at the Williston plant of the United States Reclamation Service, described in Bulletin 23^a of the Bureau of Mines.

Figure 29 shows the boiler setting and the position of two thermometers used for measuring temperatures of the flue gases. In the figure the small circles between the rear wall and the last nest of tubes are horizontal coils for preheating air used in combustion. The top half of these coils receives cold air directly from the blower and the temperature of the tubes was perhaps 100 to 150° F. The temperature of the rear drum was probably 325° F., which is the temperature of steam at 125 pounds gage pressure, the pressure carried by the boiler. The bulb of the lower thermometer was about 1 foot from the preheating coils, midway between the rear steam drum and the wall and about 3 feet below the damper.

The upper thermometer was placed about 4 feet above the damper in the hood of the stack, which extended over the uptake of another boiler, forming one battery with the test boiler. During the testing this other boiler was banked and the flue gases, which were at a very low temperature, entered the same stack as the gases from the test boiler. There was no partition separating the two halves of the hood, so that the cool gases from the banked boiler could partly mix with those from the test boiler, thereby lowering their temperature. Furthermore, the sheet-iron hood always radiated a considerable quantity of heat and was, therefore, colder than the gases on the inside. Consequently the thermometer bulb in the hood lost some heat by radiation to the sheet-iron hood and was at a lower tempera-

^a Breckenridge, L. P., Kreisinger, Henry, and Ray, W. T., *Steaming tests of coal and related investigations*, 1912, pp. 806-8.

ture than the gases passing it. Nevertheless the thermometer in the hood indicated a temperature considerably higher than that indicated by the thermometer below the damper. The thermometers

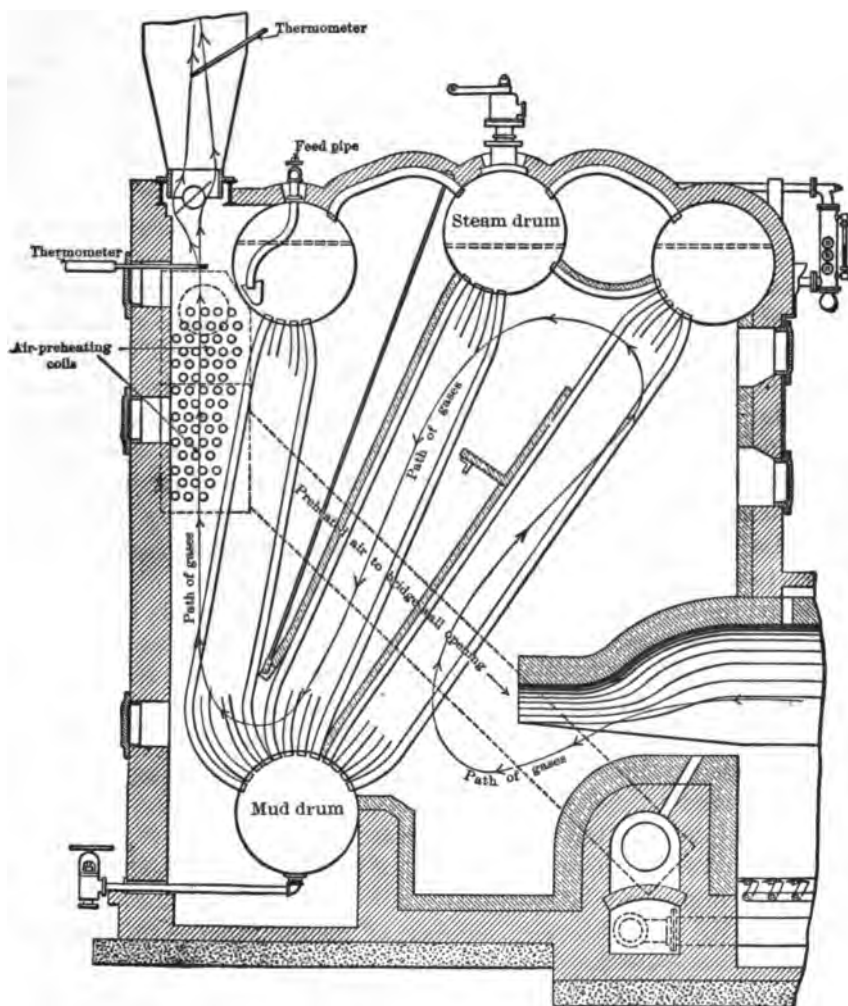


FIGURE 29.—Setting of a Stirling boiler at plant of U. S. Reclamation Service, Williston, N. Dak. Shows position of two thermometers used for measuring temperature of flue gases.

were exchanged several times, but their indication persistently bore the same relation as regards position, no matter what thermometer was used. The table following shows the temperatures as obtained by the two thermometers.

Flue-gas temperatures obtained at two places in a boiler setting.

Test No.	Reading of thermometer above damper.			Reading of thermometer below damper.		
	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.
	<i>°F.</i>	<i>°F.</i>	<i>°F.</i>	<i>°F.</i>	<i>°F.</i>	<i>°F.</i>
1.....	442	460	435	374	400	335
2.....	470	500	435	378	410	350
3.....	559	624	320	457	510	360
4.....	436	470	385	379	425	325
5.....	473	520	420	418	460	355
6.....	519	555	465	448	475	400

Often great care is taken to calibrate a flue-gas thermometer to within 1 degree, and then the instrument is placed carelessly in the uptake of the boiler setting and correct results are expected or claimed without any attention being paid to the disturbing effects of cooling surfaces. A thermometer placed in the sun would not indicate the temperature of the surrounding air, nor would a thermometer placed between two pieces of ice in a warm room indicate the temperature in the room, but some operators, when measuring the temperature of a stream of gas inside a boiler setting assume the thermometer reading to be absolutely correct because the thermometer is known to be correctly calibrated, without regard being given to the temperature of the surrounding surfaces.

After reading the preceding discussion the operator will better appreciate the importance of proper placing of a thermocouple when he desires to obtain fairly reliable measurements of the temperature of flue gases. Inasmuch as copper-constantan couples are inexpensive and easy to make he may even find it worth while to use two or three couples put in different places of the uptake of breeching and read them in rapid succession. In this event all the constantan wires can be joined together into one cold junction, and the copper wires can be led to a two or three pointed switch. With this arrangement the different couples can be read within a few seconds. Similar arrangement can be used for any number of couples placed in different boilers to compare their performance.

The radiation error practically always exists and as a rule averages about 20° F. (See figs. 1, 20, 21, and 22.)

USEFULNESS OF TEMPERATURE MEASUREMENTS.

When the instruments for measuring the temperature of gases have once been procured, and the operator has learned to use them, he can obtain with them much useful information about the performance of the boilers. Besides, the plant may contain other apparatus in which the determination of temperature is desirable. The copper-constantan couple may be used for reading temperatures up to 1000° F.

In many boiler plants the temperatures of flue gases are measured only when evaporation tests are run. The temperature of the flue gas, together with its analysis, furnish information concerning the magnitude of heat losses in the waste gases. Inasmuch as this item of heat losses is the largest one in the boiler room, and is also one that can usually be considerably reduced, the temperature measurement is an important part of the test data.

In other tests the measurement of flue-gas temperatures may be found useful. Thus by determining the flue-gas temperature before and after blowing the soot off the heating surfaces of a boiler, the detrimental effect of the soot coat on the efficiency of the boiler can be determined. Approximately, the efficiency of the boiler as a heat absorber increases 1 per cent for every 25° F. drop in flue-gas temperature, provided the furnace temperature and the rate of combustion are constant. By studying the data thus obtained, the operator can determine the best length of time between successive blowings. If scale and mud deposits on the inside of the boiler, its effect can be also fairly closely determined by measuring the flue-gas temperatures before and after cleaning the boiler. In any one investigation, considerable data should be collected and the averages used, so as to eliminate the effect of variation of other conditions, before any definite conclusions are drawn.

CALIBRATION OF THERMOCOUPLE.

The simplest way of obtaining a calibration curve for the thermocouple is to buy wires having thermoelectric properties conforming to some standard curve like the one given in figure 28. Different pieces of wire from the same roll can be relied upon to vary not more than 3 to 4 degrees, which is probably within the allowable limits of error in measuring the temperature of flue gases, because of the radiation error and the variation in temperatures of different points in the same cross section of the gas stream.

The best calibration can be obtained by sending a thermocouple to the Bureau of Standards, Washington, D. C. The price of calibration is \$7.50 per couple.* The unavoidable delay in getting such a calibration is a serious objection in many instances.

If the boiler-room operator possesses a reasonable amount of manipulative skill he can calibrate his own couples with fair results. He can use one of these two methods:

- (a) Determining three or more temperature points of the couple with known melting points of some pure metals; and
- (b) Comparing the thermocouple with a mercury thermometer of known calibration.

* Prices for calibration of various instruments are given by "Pyrometer testing and heating measurements," Bureau of Standards, Circular No. 7, 1913, 17 pp. This circular can be obtained by writing to the Director of the Bureau of Standards.

CALIBRATION BY KNOWN MELTING POINTS OF METALS AND BOILING POINT
OF WATER.

Three metals, zinc, cadmium, and tin, are well suited for this purpose, and their melting points are:

Zinc	melting point..	420° C.	787° F.
Cadmium	do.....	321° C.	610° F.
Tin	do.....	232° C.	450° F.

A fourth point can be obtained with the boiling point of water, which is 100° C. (212° F.).

PREPARING THE MOLTEN BATH.

The melting points given for these metals are those of Kahlbaum's pure metals, which may be difficult to obtain. Chemically pure metals can be purchased from any reliable chemical supply house. These are not absolutely pure, and their melting points are 2 to 5° C. lower than those given for Kahlbaum's pure metals. Therefore, if the chemically pure metals are used, a deduction of about 4° C. should be made from the melting points given above. About two pounds of each metal should be purchased, which will suffice for many calibrations.

These metals can be melted in iron crucibles heated with two gasoline blowtorches. The crucible should be surrounded with fire brick, magnesia blocks, or some other heat insulating material to prevent rapid dissipation of heat; otherwise, it might not be possible to obtain temperatures high enough to melt zinc and cadmium. Suitable crucibles for this purpose can be made of pieces of standard 1-inch iron pipe 8 inches long and closed at one end with caps as shown in figure 29. It is advisable to make separate crucibles for each metal, and to keep the metal in its crucible after calibration is completed. The use of separate crucibles will tend to prevent possible contamination of the metals and avoid the difficulties that will surely be encountered in taking the metals out of the crucibles and putting them in again when needed in future test work. All contamination should be carefully guarded against, as the melting points of the metals would be lowered, and serious errors might result. As a matter of fact, the metals are contaminated to a slight degree by being heated in the iron crucibles for a long period. However, from the experience of the authors this contamination lowers the melting points less than 1° C.

PRECAUTIONS IN MAKING READINGS.

When heating the metal the exposed surface should be covered with graphite or powdered charcoal to prevent rapid oxidation. The depth of the molten metal bath should be 4 to 5 inches before the couple is inserted. When the couple is inserted the metal will

rise to about 6 inches. The bare couple should never be immersed directly in the molten metal, but should be protected with a hard glass or a fused silica tube closed at one end. These protective tubes should be about $\frac{1}{4}$ inch in outside diameter and 10 inches long, the walls being about one-sixteenth of an inch thick. Fused silica tubes can be obtained from any firm supplying scientific materials. The arrangement of the thermocouples when placed in the bath of molten metal is shown in figure 30.

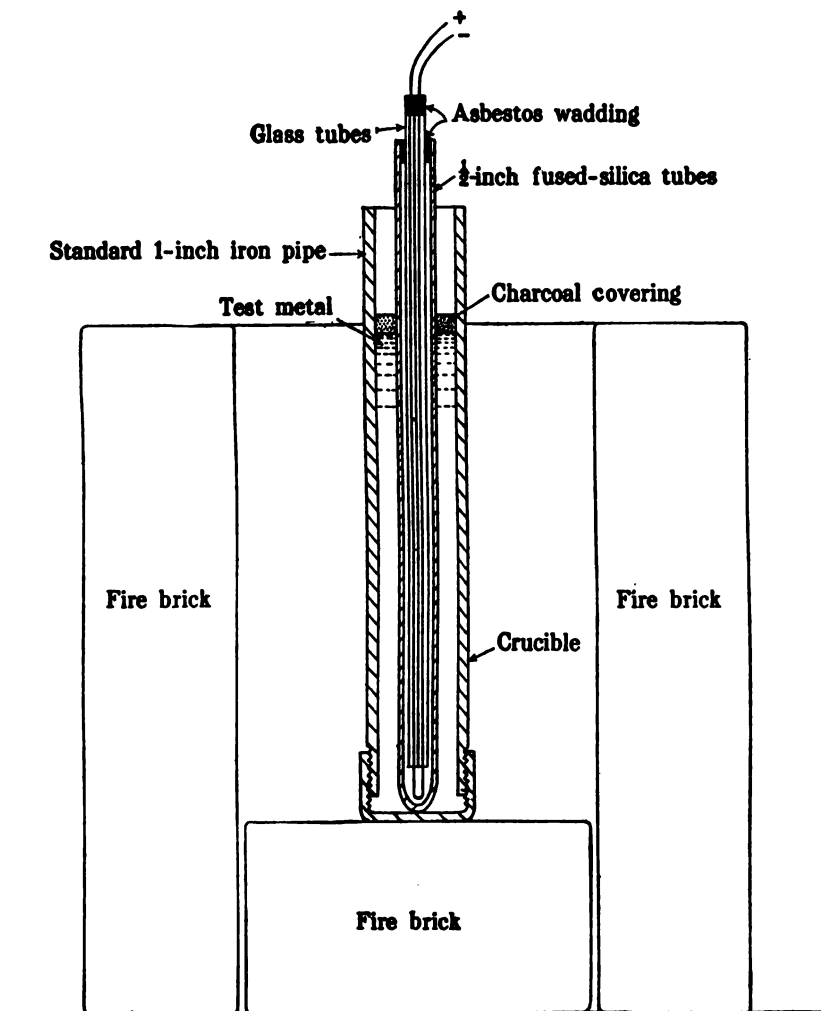


FIGURE 30.—Arrangement of apparatus for calibrating thermocouple by known melting points of metals. The crucible is surrounded with fire brick to prevent dissipation of heat from the crucible.

When calibrating the couple the cold junction should be placed in an ice bath if possible, which will avoid complicated corrections in

making the calibration curve. The metal should first be melted and then heated about 30° C. above its melting point. Then the couple, protected by the silica tube, should be inserted the full depth of the metal bath. The blowtorches should then be removed, and while the metal is cooling off readings should be taken every 10 seconds until the metal has solidified, which takes 5 to 10 minutes. The readings will show at first a marked drop in temperature, but when the metal begins to solidify the temperature will remain constant for a number of readings. After the metal has solidified there will again be a uniform drop in temperature. The constant temperature readings are the melting point of the metal. If the operator wishes to check his results, he can apply the blowtorches to the crucible and take readings while the temperature is rising. The temperature will continue to rise until the metal begins to melt, then remain constant for several readings. When the melting has been completed the temperature will again start to rise. When the operator is satisfied that he has obtained the correct melting point he should take the thermocouple and the protecting tube out of the metal bath before the latter solidifies too hard, otherwise the contraction of the metal is apt to crack the protecting tube.

PLOTTING THE CALIBRATION CURVE.

If the temperature readings are plotted as ordinates and the time as abscissas a curve like the one shown in figure 31 is obtained. The flat part of the curve is the melting temperature of the metal and is one of the points for the calibration curve.

The boiling point of water is easy to determine. The thermocouple is placed unprotected in a bath of boiling water to a depth of about 8 inches. With a given barometric pressure the temperature indication remains constant as long as the water is boiling.

The calibration curve of the couple is obtained by plotting the known melting temperatures of the metals and the boiling point of water as ordinates, and the corresponding millivolts obtained by the determinations as abscissas. A smooth curve drawn through these points gives the relation between the millivolts and the temperature of the couple. After a little experience four points on a curve can be obtained in three or four hours.

CALIBRATION BY COMPARISON WITH HIGH-READING MERCURY THERMOMETER.

If a good high-reading mercury thermometer is available a copper-constantan thermocouple can be calibrated by comparison with the thermometer. The two instruments can be immersed in a hot oil bath and read simultaneously. The oil used for this purpose should have

a high boiling point so that it is possible to obtain temperatures of 600° or 650° F. Gas-engine cylinder oil is well adapted for such calibration. The oil can be heated in a vessel made of a piece of 4-inch iron pipe about 16 inches long and closed at one end with a cap. The heating should be done with a fire that can be easily controlled. A portable forge is well suited for this purpose. The vessel must be securely suspended over the fire so that there is no danger of its tipping over. The forge should be placed where the smoke would not be objectionable. The oil always contains some lighter constituents which should be boiled off before the instruments are

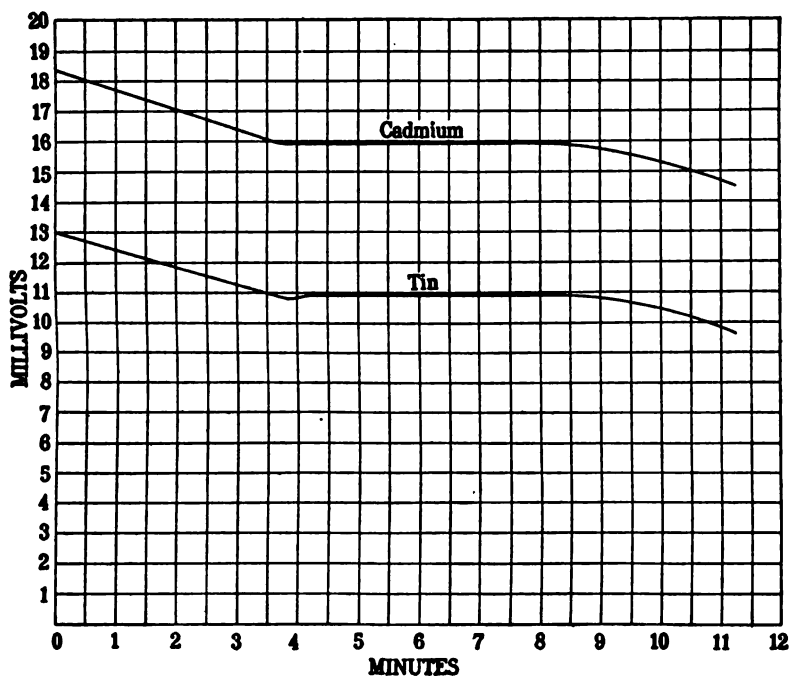


FIGURE 31.—Curves showing method of obtaining the melting point of a metal from a series of readings. The readings are taken while the temperature is falling.

immersed in the oil bath; otherwise the operator exposes himself to inconvenience from frothing and flaming of the oil, and to the danger of breaking the thermometer. The vessel is filled to a depth of about 12 inches with the oil and slowly heated. As the temperature rises the lighter constituents of the oil evaporate and the oil froths over and usually flashes up and burns. The operator need not be alarmed over this flaming. While the frothing continues the rate of heating should be reduced so as to give the light oil constituents time to boil off slowly. When the frothing stops the rate of heating can be again increased. The operator can ascertain approximately the

temperature of the oil bath by dipping in the thermometer when each of the frothing spells subsides. If too much oil has been wasted during the frothing, it may be necessary to add more to keep the level of the oil within about 4 inches of the top of the vessel. Otherwise if the level is too low it is difficult to read the thermometer and at the same time have sufficient stem immersion.

After several of the frothing spells and perhaps additions of the oil the bath reaches a temperature of about 650° F. It is then ready for use for calibration, and the instruments to be compared are immersed. The thermometer and the couple are tied together in such a way that the bulb of the thermometer and the hot junction are close together; this helps to keep the two at the same temperature. They should be immersed in the oil to the greatest depth that will still permit the operator to read the thermometer. Between successive readings the bath should be thoroughly stirred to keep the oil of uniform temperature the entire depth. The two instruments should not be used as a stirrer; a flat iron rod can be used for this purpose. It is better to read the instruments while the temperature of the oil is constant or while it is slowly dropping, because under these conditions it is easier to keep the oil at the same temperature throughout the depth of the bath and the chances of the oil frothing over are avoided. Several readings of the two instruments should be taken in rapid succession, then the temperature of the oil bath can be allowed to drop 50 to 100° F. and another series of readings taken; thus in several such steps the whole range of the thermometer can be covered. During the reading of the high points the temperature is apt to change quickly, therefore it is advisable to have two observers, one reading the thermometer and the other the thermocouple. At the lower points the temperature changes slowly and one observer is able to read both instruments. During such calibrations the cold junction of the couple should be kept at the temperature of melting ice if possible. After the calibration is completed the oil should be preserved for future use, thus saving oneself the trouble of boiling out the light oils from a fresh supply of oil.

The calibration curve is obtained by plotting the temperatures of the thermometer as ordinates and the readings of the potentiometer in millivolts as abscissas.

The same apparatus and method can be used for comparing two thermometers.

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DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

TECHNOLOGY OF SALT MAKING IN THE
UNITED STATES

BY

W. C. PHALEN

[In cooperation with the United States Geological Survey]



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PREFACE.

This report on the technology of salt production in the United States is the outcome of studies that have extended over several seasons and is based on work undertaken primarily in connection with the Government's efforts to find deposits of soluble potash salts in the United States. Nearly every active salt plant in the United States has been visited, the source of supply and the methods of extracting the salt from the brine have been studied, and hundreds of samples collected for analysis. The results of the work have been prepared for publication in two parts. One of these is to be published by the United States Geological Survey and relates to (a) the geology of salt deposits, (b) the theories connected with their origin and formation, (c) the chemistry of the salt beds and natural brines, and (d) the statistics of salt production in the United States. The part embraced by this report, published by the Bureau of Mines, relates to processes of technology.

Though the literature contains many descriptions of the salt industry in different parts of the United States, few of them treat in detail the technology of salt making. Most of the reports present information on the industry in particular States.

In recent years general reports on salt have been issued in English, but these have related to English and Canadian practice, and United States methods have been passed over with descriptions entirely inadequate to present-day progress. The work of T. M. Chatard, which relates chiefly to the industry in the United States, was written 30 years ago. The character of the machinery, the quality of the labor, and the use of labor-saving devices have undergone profound changes since that report was written. The remarkable development of mechanically-raked grainers and the establishment of the vacuum-pan process illustrate the advancement made. In some of the modern grainer and vacuum-pan plants the salt is not touched by hand from the time that it crystallizes from the brine till it is ready to be wheeled into the cars for shipment to consumers.

The importance of the salt industry needs no comment. The domestic output in the United States in 1915 was 5,352,409 short tons, valued at \$11,747,686. This industry is scattered over 14 States, distributed from coast to coast and from the Great Lakes to the Gulf. Competition has been keen in it, and this, together with the low value of the commodity, prevents its transportation to considerable distances except where local prejudice favors a certain brand. This competition has led to loss.

The general view of the industry, that Mr. Phalen was enabled to obtain from his visits to all the operating plants in the United States

enabled him to draw certain general conclusions with reference to the industry. One of these was the great excess of plant capacity as compared with the domestic requirements. The consensus of opinion seemed to be that much more salt was being produced than could be marketed, estimates of overproduction ranging from 20 to 50 per cent. The facts that large, up-to-date plants were not working at full capacity, that others were working at half time or half capacity, and that others were either temporarily or permanently closed, are significant to those planning to enter the salt business.

The rapid deterioration of the equipment also deserves consideration. The wear and tear on all salt-making machinery is heavy. If a plant is allowed to remain idle for any considerable time it is well nigh ruined. For this reason it may often be cheaper to make salt for a season without profit than to shut down. In figuring costs and basing selling price on them some producers have not provided for the rapid deterioration of plant, and this, together with overproduction, has caused heavy losses among salt manufacturers during the past decade.

Mr. Phalen points out the possibilities of utilizing the residual bittern (mother liquor) from salt making, and especially the recovery of potash and magnesium salts. Along the California coast and on the shores of Great Salt Lake, the mother liquors contain considerable quantities of these salts. As the cost of magnesium salts on the Pacific coast has been high during the war, and as the potash salts for fertilizer have been difficult to procure recently at any price, the value of these mother liquors should be appreciated, and seemingly this fact is beginning to be realized.

The report presents a valuable series of analyses made by W. B. Hicks, of the United States Geological Survey, of representative samples of natural brines. Most of these brines are now worked for salt, bromine, and calcium chloride, but some of them, for example, in northern Ohio and parts of Michigan, have never been used. These brines deserve careful investigation as a possible basis of chemical industries. The report also includes:

1. An outline of the general distribution and character of the salt deposits of the United States, which is inserted because all the readers of the report will probably not have access to the Survey's complementary report.

2. A detailed description of the different methods of salt making—by solar evaporation, direct heat (including the open-pan process), and steam evaporation (including grainer and vacuum-pan practice).

3. An outline of the manufacture of bromine from natural brines, and a description of the preparation of calcium chloride.

VAN H. MANNING,
Director.

TECHNOLOGY OF SALT MAKING IN THE UNITED STATES.

By W. C. PHALEN.

INTRODUCTION.

During the search for deposits of soluble potash salts in the United States, carried on by the United States Geological Survey, much information was collected on the salt resources and industry of the United States. The more important features of the information thus gathered, compiled, and digested may be classified under five headings, as follows:

1. Geology of the salt deposits of the United States.
2. Theories relating to the origin and formation of salt deposits.
3. Chemical composition of saline materials in the United States, principally rock salt and natural and artificial brines.
4. Statistics of salt production in the United States.
5. Technology of salt production.

The first four items are not discussed in this report, but their treatment will comprise a separate report published by the Geological Survey,^a which will supplement this report, relating to salt-making processes, and will describe comprehensively the salt resources of the United States. Persons desiring a copy of that report should apply to the Director of the United States Geological Survey, Washington, D. C.

In addition to the discussion of processes, this report gives a brief description of the more important sources of salt in the United States. This description has been abstracted from the much lengthier description contained in the report to be published by the Geological Survey.

FIELD WORK DONE.

The field investigation of the sources of salt was made chiefly in 1911 and 1912, but salt-making processes, or technology, was further studied in 1916, with a view to bringing the discussion of that subject up to date.

The field work extended over the western part of New York and included visits to operating plants in Wyoming, Livingston, Genes-

^a Phalen, W. C., Salt resources of the United States: U. S. Geol. Survey Bull. 699. In course of publication.

see, and Tompkins Counties. Every active plant in the lower peninsula of Michigan was visited, including plants in Midland, Saginaw, Bay, and Isabella Counties, where are natural brines containing bromine in commercial quantity, and bromine and other chemicals, including magnesium salts, are now obtained. The process of obtaining bromine, and the possible utilization of these and other natural brines containing bromides, lime, and magnesium salts, is discussed on subsequent pages.

Such natural brines are found at Malden, in the Kanawha Valley, W. Va., and along Ohio River in the vicinity of Pomeroy, Meigs County, Ohio, and at Mason and Hartford, Mason County, W. Va. They also underlie a large area in northern Ohio, including the region around Akron, Barberton, Wadsworth, Rittman, Cleveland, and Fairport Harbor. The brines in northern Ohio have never been worked, and, indeed, great care has to be exercised that they do not get into the salt wells and ruin them by polluting the brine. The different localities mentioned have been visited in connection with this work, and where the brine is being utilized the methods of salt making were studied. Samples were collected for analyses in most places where they could be procured.

The Kansas salt field and the salt-producing localities in Louisiana and Texas were visited.

The field work during 1912 consisted chiefly of visits to salt-producing districts in the far Western States, including the shore of Great Salt Lake and the salt-producing localities south of Salt Lake in Sevier, Sanpete, and Juab Counties, Utah, the solar evaporation plants that were in operation on the east and west sides of San Francisco Bay in Alameda and San Mateo Counties, Cal., and the solar evaporation plants in the southern part of the State, near Long Beach, Los Angeles County, and on San Diego Bay, San Diego County.

ACKNOWLEDGMENTS.

The writer takes this opportunity to thank his many friends in the industry who have so generously contributed both time and information. Specific credit is due his former colleagues in the Geological Survey, Messrs. H. S. Gale, R. K. Bailey, W. B. Hicks, and the late R. B. Dole. Acknowledgments are cordially made to George B. Willcox, president of the Willcox Engineering Co.; S. M. Lillie, Philadelphia, Pa.; A. G. Dawson, of the Manistee Iron Co., Manistee, Mich.; the Zarembo Co., Buffalo, N. Y.; the Swenson Evaporator Co., Chicago, Ill.; the Brecht Co., St. Louis, Mo.; the Bay City Iron Co., Bay City, Mich.; the Sanborn Evaporator Co., New York City; the Wheeler Condenser & Engineering Co., Carteret, N. J.; and the Oscar Krenz Copper & Brass Works, San Francisco, Cal.

MINERALOGY OF SALT.

Common or rock salt is known to mineralogists as halite. It is the chloride of sodium, composed of 39.4 per cent chlorine, which in its free state is a gas, and 60.6 per cent sodium, which in its free state is a metal. Halite is rather brittle and has a conchoidal fracture. Its hardness is 2.5; its specific gravity ranges from 2.1 to 2.6, that of pure crystals being 2.135; its index of refraction is 1.5442; and it is highly diathermous. It seldom occurs perfectly pure, but is mixed with a variety of other saline minerals—such as gypsum, anhydrite and, in Germany, carnallite, kieserite, and polyhalite—or is associated with shale and sandstone.

Halite crystals are isometric and usually form cubes, commonly distorted and in cavernous shapes termed hopper-shaped crystals. Halite also occurs massive with a granular to compact structure. Masses with perfect cubical cleavage are common, as also those with fibrous texture which are said to be pseudomorphous after gypsum. Rock salt has a vitreous luster, and when pure is transparent and colorless. The different shades of color are due to impurities which impart yellow, red, brown, blue, and purple hues, and are responsible for the varying degrees of translucency. Salt is readily soluble in water, and its characteristic taste is known to all.

THE USES OF SALT.

Salt is largely used for culinary purposes and also in the meat-packing, fish-curing, dairying, and other industries to prevent deterioration. It is also used extensively for refrigerating purposes, a familiar example being the making of ice cream. The treatment of gold and silver ores by chlorination also consumes some salt. In the form of brine it is largely used in the chemical industries in the preparation of soda ash, caustic soda, and various other chemicals containing a sodium base.

Besides the uses given above, other miscellaneous uses are: To form a glaze on pottery; in enameling and pipe works; salting cattle; curing hides; making pickles; and clearing oleomargarine. Recent experiments have indicated that it may prove of value in aiding the recovery of potash salts as a by-product in the Portland cement industry.

TYPES OF OCCURRENCE.

Salt is widely distributed and in many places forms beds of sufficient size to constitute true rock masses. It is also found in solution in salt springs, in the water of the ocean, and in inland salt lakes or seas, as in the Great Salt Lake and the Dead Sea. Interstratified deposits of rock salt have been formed by the gradual evaporation

of bodies of sea water cut off from the main ocean. The salt water of inland salt lakes or seas, like the Great Salt Lake and the Dead Sea, has been concentrated by evaporation. In such inclosed bodies of salt water the minerals in solution crystallize out in the order in which the solution becomes saturated with the various solid salts. This order depends partly on the relative quantities of the various constituents originally in the water and partly on the solubility of the precipitated salts.

Rock salt is of such general occurrence that a list of the localities where it is found would include almost every civilized country. In the United States there are extensive and valuable deposits of salt in central and western New York, in Pennsylvania, Ohio, Michigan, Virginia, Kansas, Louisiana, Texas, Nevada, Utah, Arizona, New Mexico, California, Idaho, Wyoming, and probably in several other States. Salt springs and wells abound in the neighborhood of the salt deposits, and these, as well as the waters of salt lakes and sea water, constitute the sources of the commercial product.

SALT DEPOSITS OF THE UNITED STATES.

GENERAL DISTRIBUTION AND CHARACTER.

Of the useful minerals found in the United States perhaps none occurs in seemingly greater abundance or is more widely distributed than common salt. The various modes of occurrence include crystalline layers interbedded with other sediments, which may have been chemically precipitated, as gypsum, or may be ordinary clastic sediments, as sandstone and shale; in beds of dry or nearly dry lakes, marshes, or alkali flats; or in the form of dissolved salt, in natural brines or bitterns issuing from salt springs or accumulated in salt lakes or ponds.

In the eastern part of the United States salt does not lie at the surface of the ground, as in many parts of the West. In New York, western Pennsylvania, Michigan, Ohio, Kansas, Virginia, Louisiana, New Mexico, and eastern and northwestern Texas salt forms rock deposits well below the surface, where it is protected from the solvent action of rain and ground water by a thick mantle of impervious beds. In the far-western States, Idaho, Wyoming, west Texas, New Mexico, Arizona, Nevada, and California, many important saline deposits are exposed at the surface because the climate is arid. Thus the United States may be divided into east and west parts with reference to its salt resources, the division being not only geographic, but climatic.

In the Western States are many localities having large and important salt deposits, the presence of salt being attested by many place names. The greater part of Nevada, large parts of Utah and California, and small parts of Oregon, Idaho, and Wyoming are included within the Great Basin Region, so-called. In this region lie the drainage basins of the former Lake Lahontan and Lake Bonneville. These basins have been studied by Gilbert ^a and Russell.^b The conclusions of these two men regarding the salines deposited from the waters of these lakes, their accumulation, disappearance from the surface, and the possibility of finding them below the surface are discussed in the report that will be published by the United States Geological Survey.

^a Gilbert, G. K., *Lake Bonneville*: U. S. Geol. Survey Mon. 1, 1890, 438 pp.

^b Russell, I. C., *Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada*: U. S. Geol. Survey Mon. 11, 1885, 288 pp.

NEW YORK.

EARLY DEVELOPMENTS.

Rock salt was discovered in New York in 1865 at the village of Vincent, in western Ontario County. The importance of the find was not fully appreciated until after rock-salt beds had been found in other places. Early in 1878 one of several test wells sunk in western New York in a search for oil encountered a bed of rock salt 70 feet thick at a depth of 1,279 feet, a mile south of Wyoming. This well became known as the "pioneer well." Three years later, in March, 1881, works with the small capacity of 40 barrels a day were erected, and salt was first made from artificial brine. Shortly after this discovery successful exploration took place at Le Roy, north of Wyoming, and salt was first made at Le Roy in the spring of 1884.

In the meantime progress was made in another part of the State. In August, 1881, a company of citizens of Warsaw began to sink a well near the Buffalo, Rochester & Pittsburg Railroad, in the northern part of the town, and in October of that year found a bed of salt and shale 111 feet thick at a depth of 1,520 feet. Eighty feet of the bed proved to be salt. An abundant supply of water from which artificial brines could be made was also encountered. It was soon shown that the artificial brine was fully saturated, of great purity, and practically unlimited in quantity. The development of the salt industry in this general locality in the Oatka Valley was very rapid in 1883. In that year salt was found in the Genesee Valley by a well near the shaft of the Retsof Salt Mines, 10 miles directly east of the Pioneer well in the Oatka Valley. In September, 1885, a shaft 9 by 12 feet reached rock salt near Greigsville, at a depth of 996 feet. Many wells and a few other shafts were put down in the Genesee Valley during the following years.

The discovery of rock salt at Wyoming revived interest in the search for the bed that geologists had asserted must exist in the higher land south of Syracuse, and in 1881 a well was sunk at Jamesville, 7 miles southeast of the head of Onondaga Lake. In 1882 another well was sunk at Cedarvale, 7½ miles southwest of the Indian land reservation. Rock salt was not found in either of these wells. In 1884 two wells were put down near Onondaga Salt Springs, one by private parties and the other by the State. No rock salt was found in the Salina formation by either of these wells. In 1885 a test well sunk at Ithaca to a depth of 3,185 feet found salt, and a careful record was made of it. The stratigraphy of the Ithaca well has been described by Prosser.^a In 1886 a well at Morrisville, Madison County, struck rock salt. This well marks the most easterly point at which rock salt has

^a Prosser, C. S., The thickness of the Devonian and Silurian rocks of western central New York, *Am. Geologist*, vol. 6, October, 1890, pp. 202-203.

been found in the State and the most northerly point east of Genesee River, with possibly a single exception.

In 1888 the Solvay Process Co., of Syracuse, in searching for a larger and cheaper supply of brine for its great soda-ash plant at Syracuse, began a well in the south end of the valley of Onondaga Creek in the town of Tully, 17 miles south of Syracuse. This well was abandoned after it had passed through 400 feet of glacial drift, but another well a quarter of a mile farther east found at a depth of 1,216 feet a bed of rock salt 45 feet thick. In 1889, 10 new wells were put down; in 1890, 10 more; and in 1891, 9 more, all on the east side of the valley. In 1895 and 1896, 11 additional wells were drilled on the opposite side of the valley, making a total of 41 wells drilled to the salt bed there by this company. Forty of these wells are connected by iron pipes with Tully Lakes. The lake water flows by gravity to the salt and becomes saturated with it. This brine formerly flowed through other pipes into a large main that conveyed it to Syracuse, where the works are 360 feet lower than the mouth of the lowest well, but owing to the loss by this method the wells are now pumped.

In 1891 a well was sunk to the salt bed at Ludlowville, Tompkins County, and a second well was put down in 1892. In 1895 another well was drilled at Ithaca, north of the well put down in 1885. In 1893, 1894, and 1896 wells were sunk at Watkins, Schuyler County, and salt is now being made at that place. A shaft is reported to have been begun on the shore of Lake Cayuga south of Ludlowville in 1916.

RELATIVE IMPORTANCE OF NEW YORK FIELD.

During the past few years New York has ranked second among the States in both quantity and value of salt produced. The industry includes both the mining of rock salt and the evaporation of brine by the solar, open-pan, grainer, and vacuum-pan processes.

POSITION OF FIELD.

The salt field in New York is distinct from that in the near-by State of Ohio, but is related to the deposits in the Province of Ontario, Canada. The salt-bearing Salina formation, outcropping in a belt approximately 12 miles wide at Niagara River, extends eastward across the central tier of counties in New York to a little south of Oneida Lake. The outcrop then turns southeast, narrowing gradually, and terminates in the vicinity of Schoharie River, Schoharie County. Its greatest width, about 20 miles, is at the foot of Cayuga and Seneca lakes. Salt making is confined to the region south of this outcropping belt, that is, in the direction of the dip of the beds, because the salt is leached from outcropping beds in this region of abundant

rainfall. A map presented in Bulletin 669^a of the United States Geological Survey showing the outcrop of the Salina formation brings out these facts and shows the places in the State where salt has been found in wells and shafts.

EXTENT OF DEPOSITS.

The area known to be underlain with rock salt comprises a corner of Genesee County south of LeRoy, the eastern half of Wyoming County, nearly the whole of Livingston County, and the part of Ontario County west of Canandaigua Lake and chiefly south of the New York Central Railroad. Late reports indicate that to the west, in Erie County, rock salt has been found at Eden Valley, Springville, Perry, and Gowanda,^b and in a gas well between Cattaraugus and Gowanda,^c in Cattaraugus County.

East of Canandaigua Lake the borings at Dundee, Watkins, Ithaca, Ludlowville, and Tully all reached the rock-salt beds. The area underlain by rock salt west of Canandaigua Lake is computed by Bishop^d to comprise 1,100 square miles. In view of discoveries made since Bishop's report, his estimate is probably far too low. The area underlain by salt east of Canandaigua Lake must be fully as large as that to the west, if not larger. The northern limit can be assigned only approximately, owing to the rock salt being dissolved near the surface. The southern limit is not known and may never be accurately determined, as the thickness of the cover of Salina formation increases in that direction, but the salt is known to extend at least as far south as the vicinity of Pittsburgh, Pa. The persistence of the salt to the south in New York, however, is indicated by the wells at Ithaca, which reach the salt at a depth of 2,200 feet, and by test borings in northern Cattaraugus and Allegany Counties, which encountered salt at over 3,000 feet. The boring at Canaseraga, Allegany County, penetrated 75 feet of rock salt, beginning at a depth of 3,050 feet.^c

The northern limit, as shown by the outcropping Salina strata, is approximately defined by a line drawn from a point south of Oneida Lake westward to Buffalo. South of this line, the deposits lie progressively deeper in accordance with the dip of the strata, which ranges from 40 to 50 feet per mile. The most eastern point at which salt has been found is Morrisville, Madison County. Between this and Lake Erie salt has been found in almost all of the central tier of counties.

^a Phalen, W. C., Salt resources of the United States: U. S. Geol. Survey Bull. 600. In course of publication.

^b Newland, D. H., Mining and quarry industry: New York State Museum Bull. 166, August, 1913, p. 57.

^c Newland, D. H., Mining and quarry industry: New York State Museum Bull. 174, December, 1914, p. 66.

^d Bishop, I. P., Report of the New York State Geologist, vol. 5, 1885, p. 34.

MICHIGAN.

RELATIVE IMPORTANCE OF MICHIGAN SALT INDUSTRY.

During the past few years Michigan has ranked first among the States in both quantity and value of salt produced. Salt in Michigan is obtained from two distinct sources—rock salt and natural brine—and is produced by the open-pan, grainer, and vacuum-pan methods of evaporation. The industry based on rock salt is of much greater importance than that based on natural brine.

POSITION OF SALT FIELDS.

Salt is made in three distinct parts of the State. The producing districts are situated (1) in the southeastern part of the State along Detroit and St. Clair Rivers, (2) in approximately the central part of the Lower Peninsula, especially in the Saginaw Valley, and (3) along the western coast of the Lower Peninsula.

DEPTH TO SALT BEDS.

In the southeastern part of Michigan and to the north along St. Clair River a great many wells have been sunk to the salt beds. Records of these wells are given in United States Geological Survey Bulletin 669.^a The depths to the salt beds are shown in the accompanying table;

Depths to salt beds in eastern Michigan.

Location.	Depth in feet.
Marine City, well No. 1.....	1, 604-1, 637
Marine City, well No. 2 (first bed).....	1, 634-1, 735+
Marine City, well No. 3.....	{ 1, 622-1, 637 1, 642-1, 662 1, 672-1, 737
Marine City, well No. 4.....	{ 1, 570-1, 590 1, 600-1, 630
Marine City, 2½ miles north of, well No. 6.....	1, 600
Marine City, probably west of, well No. 7.....	{ 1, 620-1, 650 1, 675-1, 775
Petrolia, Ontario, 18 miles from Port Huron (in Monroe group)	1, 199-1, 251
Port Huron, well No. 12 (Monroe group and { Salina formation).....	{ Just above 1, 600 At 1, 600 Above and below 1, 700
Port Lambton, Ontario, 5 miles northeast of Algonac.....	1, 710-1, 720
Royal Oak, well No. 2.....	{ Highest, 1, 543-1, 640 Lowest, 2, 315-2, 475
St. Clair.....	1, 630-1, 660
St. Clair, 5 miles below.....	1, 500
St. Clair, one-half mile east of (in the Monroe group).....	1, 620-1, 650
Wyandotte (bands of salt).....	730-1, 235

^a Phalen, W. C., Salt resources of the United States: U. S. Geol. Survey Bull. 669. In course of publication.

No rock salt occurs in the southwestern part of the State, but it is found to the north, at Ludington and Manistee. At Frankfort, still farther to the north, in Benzie County, wells through the Salina, the salt-bearing formation, did not strike salt, nor even a strong brine. It is likely that Frankfort is just outside the borders of the ancient sea in which the salt was deposited. Likewise the St. Ignace and Cheboygan wells show no salt. The following log shows the beds that a typical well penetrates at Ludington.

Log of salt well put down by J. S. Stearns, at Ludington, Mason County, Mich.^a

[Ten-inch casing, 204 feet; water (53° F.) at about 300 feet; 8-inch casing to rock.]

	Material.	Thickness, feet.	Depth, feet.
Pleistocene:			
	Sand.....	198	.....
	Clay, pink, calcareous.....	68	266
	Gravel.....	94	360
	Clay, pink, calcareous.....	155	515
	Gravel.....	61	576
	Limestone, with 15 feet of porous granular limestone and salt water 35 feet below the casing.....	74	650
Coldwater:			
	Shale, blue.....	550	1,200
Antrim:			
	Shale, black.....	200	1,400
Traverse group:			
	Limestone, brown.....	25	1,425
	Shale, blue.....	35	1,460
	Limestone, brown, oily, with hydrogen sulphide.....	40	1,500
	Limestone, pure (Dundee?).....	250	1,750
	Dolomite, brown, sandy.....	160	1,910
	Shale, calcareous.....	90	2,000
Monroe group:			
	Dolomite.....	25	2,025
	Limestone.....	25	2,050
	Dolomite.....	25	2,075
	Sandstone (Sylvania?).....	100	2,175
	Dolomite, sandy, and anhydrite.....	121	2,296
	Salt.....	8	2,304

At Manistee are a number of wells 300 to 400 feet shallower than the Stearns well. The depths to salt are shown by some of the records of the Ludington and Manistee wells, as follows:

Depths to salt at Ludington and Manistee, Mich.

Location.	Depth to salt, feet.
Ludington, well No. 1.....	2, 195
Ludington, 1 mile south of.....	2, 242-2, 260
Ludington, well No. 3.....	1, 965-2, 001
Manistee, well No. 1.....	{ 1, 978-1, 985 1, 988-2, 012
Manistee, well No. 2.....	{ 1, 900-1, 904 1, 912-1, 942
Manistee, well No. 3.....	1, 988
Stronach.....	1, 930-1, 964

^a Lane, A. C., Notes on the geological section of Michigan: Michigan Geol. Survey Tenth Ann. Rept. of 1908, 1909, pp. 91-105.

Another area which contains rock salt in some quantity, but has not yet been developed, is about Alpena, in the northeastern part of the Lower Peninsula, on the shores of Thunder Bay, an arm of Lake Huron. Here five beds of salt, with streaks of gypsum and anhydrite, are known, their aggregate thickness being about 300 feet.

OHIO.

RELATIVE IMPORTANCE OF OHIO SALT INDUSTRY.

Ohio has ranked third among the States in recent years in both the quantity and the value of the salt produced. Both salt beds and natural brines are utilized and the product is made by the common processes of evaporation, the grainer and vacuum-pan processes. No rock salt is mined. Considerable brine obtained from beds of rock salt is utilized in the manufacture of soda. Bromine and calcium chloride are also obtained from the natural brines along the Ohio River, and reports indicate that an increase in chemical industries may soon be expected there.

POSITION OF FIELDS.

Ohio salt at present comes from two distinct districts, one in the northeastern and the other in the southeastern part of the State. The southeastern district at present is included entirely within Meigs County and is coextensive with that in West Virginia on the opposite side of Ohio River. The northeastern district comprises Cuyahoga, Medina, Summit, Wayne, and Lake Counties.

SALT DEPOSITS IN NORTHEASTERN OHIO.

Though the salt-producing area in northeastern Ohio is large, salt production thus far has been restricted to Cuyahoga, Summit, Medina, Lake, and Wayne Counties. Salt is not produced as such in Lake County, the brines produced by the Diamond Alkali Co., at Fairport Harbor, being made into other sodium compounds. That the salt beds extend farther east than the producing wells is shown by the following record of the Hadsell well near Cortland, Trumbull County:^a

^a Bownocker, J. A., Salt deposits and the salt industry in Ohio: Ohio Geol. Survey, ser. 4, Bull. 8, 1906, p. 42; Ohio Geol. Survey Econ. Geol. Bull. 8, vol. 9, 1906, pp. 9-42.

Log of Hadsell well, near Cortland, Trumbull County, Ohio.

Material.	Thickness, feet.	Depth, feet.
Drift.....	40	.....
Shale.....	60	100
Berea grit.....	160	260
Shales, Bedford and Ohio.....	2, 386	2, 656
Limestones, Corniferous and Monroe.....	583	3, 239
Salina formation:		
Rock salt.....	12	3, 251
Limestone.....	5	3, 256
Rock salt.....	2	3, 258
Limestone.....	3	3, 261
Rock salt.....	10	3, 271
Limestone.....	49	3, 320
Rock salt.....	29	3, 349
Limestone.....	10	3, 359
Rock salt.....	52	3, 411
Shale, white.....	18	3, 429
Limestone.....	36	3, 465
Rock salt.....	10	3, 475
Limestone.....	50	3, 525
Shale, white.....	15	3, 540
Rock salt.....	30	3, 570
Limestone.....	10	3, 580
Rock salt.....	3	3, 583
Shale, white.....	90	3, 673
Limestone.....	5	3, 678
Shale, blue.....	32	3, 710

This record shows 148 feet of rock salt. If the alternating strata of limestone are similar to those farther west in having many large holes filled with salt, then the total quantity is much in excess of 148 feet. The record shows that the salt strata extend to the eastern line of the State. Although the data from well records in New York do not warrant the statement that the salt beds of New York are coextensive with those of Ohio, the presumption that this is so is strong, as comparatively recent records have shown the existence of rock salt in Erie and Cattaraugus Counties, in localities where it was formerly considered not present. The southern limit of the salt deposits has not been determined, because the strata dip south and east, and the salt lies so deep that it has not been reached by the drill. Westward, also, the limit has not been determined, but can not extend as far as Sandusky, according to the following record obtained near that place, although too much weight must not be attached to the evidence of a single well.^a

^a Orton, Edward, Report of the geological survey of Ohio, petroleum and natural gas: Ohio Geol. Survey, vol. 6, 1888, p. 195.

Log of well, Sandusky, Erie County, Ohio.

Material.	Thickness, feet.	Depth, feet.
Drift.....	10	.....
Limestone, Corniferous.....	100	110
Limestone, Monroe and Niagara.....	970	1,080
Shale, Niagara and Clinton formations.....	105	1,185
Shale, Medina.....	175	1,360
Shale and limestone, Cincinnati.....	500	1,860
Shale, Utica.....	310	2,170
Shale, not recorded.....	40	2,210
Limestone, Trenton, at.....		2,210

Considering the area beneath which salt is known to exist, and the number and thickness of the salt beds, the conclusion seems warranted that northeastern Ohio contains enough salt to last an indefinite time at the present rate of consumption.

BRINE HORIZON IN SOUTHEASTERN OHIO.

The salt industry in southeastern Ohio centers at Pomeroy, Meigs County, where a natural brine is worked for bromine and calcium chloride, as well as salt. The depths of the wells obtaining brine have increased greatly. At first the wells were shallow, being reported as about 300 feet deep and as reaching the horizon of the first Cow Run sand, an important source of petroleum in Washington and Morgan Counties. Later the wells were deepened to get a larger supply of brine. When this proved inadequate the wells were again deepened.

The following skeleton record of a well belonging to the Buckeye Salt Co. is interesting. The well head is 25 feet below the Pomeroy or No. 8 coal.

Log of well near Pomeroy, Meigs County, Ohio.^a

Material.	Thickness, feet.	Depth, feet.
Conductor.....	58	.....
Shale.....	492	550
Sand, white and gray.....	320	870
Sand, white, and slate.....	90	960
Big salt sand.....	170	1,130
Sand and white shale.....	365	1,495
Strata unrecorded.....	50	1,545
Berea grit.....	25	1,570
Strata unrecorded.....	20	1,590

^a Brines were struck at 320 feet; density 6° B.; at 710 feet, density 9° B.; at 980 feet, density 9° B., and at 1,550 feet, density 16° B.

Another record furnished by the Liverpool Salt & Coal Co. is as follows:

Log of well at Hartford, Mason County, W. Va.

Material. ^a	Thickness, feet.	Depth, feet.
Surface to "Horseneck".....	300	.....
"Horseneck" (containing oil and gas).....	50	350
Chiefly shale.....	110	460
First Cow Run sand (much water, no oil).....	40	500
Shale, etc.....	250	750
Second Cow Run sand.....	40	790
Shale, etc.....	210	1,000
First salt sand.....	50	1,050
Shale.....	55	1,105
Second salt sand.....	60	1,165

As soon as the second salt sand was reached the brine rose in the well to a distance of 600 feet from the surface. In all, the well was drilled to a depth of 1,359½ feet, but soon partly filled. The well was to go to the Berea, but the volume of water would have required another line of casing. A very small coal seam was reported in the record, but its exact position was not given.

CHARACTER OF BRINE.

As stated in the table on page 13, the brine in the Berea was much denser than that in the overlying rocks. The quantity, however, was small, and the well is pumped from the horizon of the Big Salt sand (Pottsville), depths 1,105 to 1,165 feet in the record given above. The company has five wells, the depths varying from 1,089 to 1,590 feet, the latter penetrating the Berea. The Excelsior Co. has four wells, whose depths range from 1,100 to 1,200 feet. Wells drilled farther east go deeper, because the beds dip in that direction.

When drilling first began here the water is said to have risen nearly to the well heads and to have overflowed from some wells. As pumping progressed the reservoirs of brine were lowered, and the tubing was extended deeper into the wells.

For many years the Excelsior works have pumped from the 750-foot level. The brine is said to rise slightly when wells in neighboring plants are not in action. The density of the brine increases in the direction of the dip of the rocks—that is, to the southeast—as is shown in the following table:

Increase of density with depth of natural brine, Pomeroy, Ohio.

	Density of brine, °B.	Temperature of brine, °F.
Pomeroy Salt Works, west end of Pomeroy.....	8	61.5
Excelsior Salt Co., east end of Pomeroy.....	8.5	63
Syracuse Salt, Bromine & Calcium Works (not now operated).....	10.5	62.5

^a The names of the sands are those applied by the driller.

According to Bownocker,^a the variation in density is due to the heavier brines seeking the lower level. The variations in temperature result in part from the different conditions under which the measurements were made. The variation is also due in part to the wells to the southeast being deeper.

The quantity of brine that has been taken from these rocks is enormous, much more than the rocks could at any one time contain, and the excess has doubtless come from surrounding territory. The brine-bearing strata dip toward Pomeroy from the northwest. As the brine has been pumped from the wells, the supply has been renewed from the rocks lying at a higher level.

WEST VIRGINIA.

POSITION OF SALT FIELDS.

West Virginia is an important producer of salt from natural brines, part of which is from sandstones in the Carboniferous. These brines are also an important source of bromine and calcium chloride.

The natural brines now utilized underlie the regions along Ohio and Kanawha Rivers. The Ohio River field is coextensive with that in Ohio, Mason and Hartford, in Mason County, being the centers of the industry in this part of the State. Malden, 6 miles above Charleston, is the site of the salt, bromine, and calcium chloride industry on the Kanawha River.

The Ohio River area in West Virginia is geologically a part of the Pomeroy district of Ohio. Mason, one of the centers of the salt industry in West Virginia, is situated nearly opposite Pomeroy, and Hartford is a short distance farther up the river. The geologic occurrence of the brines at Pomeroy, Ohio, has already been discussed. (See pp. 13 and 14.)^b

KANAWHA RIVER AREA.

The record of a deep well drilled for gas on the Cool Spring Branch of Burning Springs Hollow, 2 or 3 miles from Malden, throws some light on the geological horizon from which brines are obtained on the Kanawha River near Charleston. The horizon of the mouth of the well is thought to be far from the surface at the wells near Malden. According to White,^c the Salt Sand in this record is 837 feet thick, and yields the brine that contains the salt and bromine obtained in the plant at Malden. The term "Salt Sand," as used by White, appears to be equivalent to Pottsville group.

^a Bownocker, J. A., work quoted, p. 26.

^b See also Phalen, W. C., Salt resources of the United States: U. S. Geol. Survey Bull. 669. In course of publication.

^c White, I. C., Petroleum and natural gas precise levels: West Virginia Geol. Survey, vol. 1c, 1904, p. 272.

PENNSYLVANIA.

SITUATION OF SALT FIELDS.

Salt, bromine, and calcium chloride from natural brines have been obtained in recent years on the North Side, in Pittsburgh, Pa. Early in 1914, however, the industry was discontinued because the brines became so dilute that their treatment was unprofitable.

At the salt plant four wells were in operation. One well, one of the deepest in Pennsylvania, reached a depth of 4,089.5 feet, and penetrated nearly 4,000 feet of beds that do not outcrop near by. Brine was obtained in this well at a depth of 1,405 feet, from a sand designated in the record as "salt sand." This sand is probably in the Pocono formation, of Mississippian age, and possibly is the equivalent of the Berea sandstone.^a The record of the well is as follows:

Log of the John A. Beck No. 4 gas well at Pittsburgh, Allegheny County, Pa.

Material.	Thickness, feet.	Depth, feet.
Ashes and clay.....	20	20
Gravel.....	49	69
Slate (water at 95 feet).....	30	99
Sand (drive pipe, 75 feet).....	40	139
Slate.....	81	220
Sand.....	50	270
Slate.....	15	285
Lime.....	5	290
Slate.....	89	379
Coal.....	7	386
Slate (10-inch casing, 390 feet).....	50	436
Lime.....	30	466
Slate.....	10	476
Sand.....	30	506
Slate.....	10	516
Lime.....	15	531
Sand.....	45	576
Slate.....	124	700
Sand.....	10	710
Slate (8½-inch casing, 840 feet).....	35	745
Sand, Big Injun.....	319	1,064
Slate.....	10	1,074
Sand.....	70	1,144
Slate.....	15	1,159
Sand.....	20	1,179
Slate.....	5	1,184
Sand.....	20	1,204
Slate and shell.....	46	1,395
Salt sand (salt water at 1,405 feet).....	95	1,490
Sand.....	30	1,520
Slate.....	10	1,530

^a Munn, M. J., Oil and gas fields of the Carnegie quadrangle, Pennsylvania: U. S. Geol. Survey Bull. 456, 1911, pp. 11-12.

Material.	Thickness, feet.	Depth, feet.
Sand.....	115	1, 645
Slate (6½-inch casing, 1,645 feet).....	5	1, 650
Sand (little gas at 1,655 feet).....	10	1, 660
Slate.....	50	1, 710
Sand.....	30	1, 740
Slate.....	20	1, 760
Sand (Gordon Stray?).....	10	1, 780
Slate.....	5	1, 785
Red rock.....	5	1, 790
Sand (Gordon?).....	30	1, 820
Slate.....	35	1, 855
Sand.....	10	1, 865
Slate and shell.....	60	1, 925
Sand, fifth.....	23	1, 948
Slate and shell.....	82	2, 030
Sand.....	10	2, 040
Slate and shell.....	310	2, 350
Sand.....	30	2, 380
Slate.....	110	2, 490
Sand.....	40	2, 530
Slate.....	35	2, 565
Sand.....	40	2, 605
Slate.....	195	2, 800
Sand.....	20	2, 820
Slate.....	580	3, 400
Sand.....	40	3, 440
Slate and shell.....	560	4, 000
Sand.....	40	4, 040
Slate and shell.....	49. 5	4, 089. 5

Two other records of deep wells in western Pennsylvania show that the salt-bearing formation of western New York, the Salina, extends into western Pennsylvania. One of these wells, known as the Derrick City or Bradford City well, was drilled by the Bradford Deep Well Co., 4 miles northeast of Bradford, McKean County, Pa., in 1912 and 1913. This well reached a depth of 5,820 feet, and struck four beds of salt, ranging in thickness from 10 to 47 feet. The top of the highest salt bed was at a depth of 4,490 feet, and the base of the lowest was at 4,713 feet, the salt-bearing beds thus extending through a total thickness of 223 feet.

The other deep well, known as the McDonald well, is situated about 4 miles northwest of McDonald, Washington County, Pa., some 14 miles southwest of Pittsburgh. In this well, salt water was encountered at approximately 6,825 feet, and rock salt was found in the 350-foot interval between 6,825 feet and 7,175 feet.

VIRGINIA.

The only economically important deposits of salt in Virginia are in the southwestern part of the State. These, with the gypsum deposits, underlie for 20 miles the valley of the north fork of the Holston River, and have been developed rather extensively in Smyth and Washington Counties. Two gypsum plants and one alkali works in which salt is utilized are now in operation.

The salt and gypsum deposits, according to Eckel,^a lie within the lower member of the Greenbrier (Newman) limestone, which is 600 to 1,000 feet thick, and consists of shaly limestones with one or more beds of gypsum underlain by blue shales, or "slates," that are in turn underlain by shales or shaly limestones containing thick beds of rock salt. This lower member of the Newman limestone seems to be local, as it has been recorded only in this region.

None of the earlier wells drilled on the Robertson property southwest of Saltville show an appreciable quantity of salt, perhaps because there was no salt where the drilling was done, or because drilling stopped before reaching the salt. Although no records of the wells are obtainable, salt was reached at a depth of 800 feet, and it is said that the aggregate thickness of the rock-salt beds penetrated is 175 feet.

In a description of the area Stose^b divides the Mississippian rocks there into three formations as follows: (1) An upper limestone called the Newman limestone, with a thickness of about 3,325 feet; (2) the Maccrady formation of shales, sandstones, and limestones, with a thickness of 1,025 feet, more or less; and (3) the Price sandstone, with a thickness of 327 to 424 feet. The most striking fact is that the gypsum and salt deposits of the district have been found in quantity only in the shales of the Maccrady formation along the Saltville fault.

Stose differs from Eckel in regard to the origin of the salt and gypsum deposits, believing them to be largely secondary and not primary, and to have been derived from calcareous-argillaceous sediments originally containing disseminated gypsum and salt which precipitated in a partly inclosed arm of the sea. The disseminated salt and gypsum was subsequently concentrated in the same formation by ground waters circulating along the fault zone between the Carboniferous and Cambrian rocks.

^a Eckel, E. C., Salt and gypsum deposits of southwestern Virginia: U. S. Geol. Survey Bull. 213, 1903, pp. 406-416.

^b Stose, G. W., Geology of the salt and gypsum deposits of southwestern Virginia: U. S. Geol. Survey Bull. 530, 1912, pp. 232-255.

Following is a generalized record of a typical well on the property of the Mathieson Co. at Saltville, Smyth County: ^a

Generalized record of typical well of Mathieson Co., Saltville, Smyth County, Va.

Material.	Thickness, feet.	Depth, feet.
Limestone and shale.....	26	26
Shale and gypsum.....	195	221
Mostly shale with gypsum and some rock salt.....	359	580
Mostly limestone with shale, gypsum, and rock salt.....	215	795
Mostly shale with gypsum and rock salt.....	100	895
Mostly rock salt with little shale.....	197	1,092

KANSAS.

RELATIVE IMPORTANCE OF KANSAS SALT INDUSTRY.

In 1915, Kansas ranked fourth among the States, both in the quantity and the value of the salt made that year. The State produces much rock salt and also evaporated salt made by the open-pan, grainer, and vacuum-pan processes.

POSITION AND EXTENT OF SALT DEPOSITS.

In a small part of north, middle, and south-central Kansas salt occurs in salt marshes as brine. During the dry season this brine evaporates, leaving rock salt in the so-called salt plains. Salt from this source is not at present utilized, so far as known.

The rock salt now worked at Lyons and Kanopolis, and supplying the brines at Ellsworth, Hutchinson, Sterling, Lyons, Anthony, and other places, lies well below the surface. Salt in the form of brine also occurs in certain beds of the Permian and Pennsylvanian ("Coal measures") in the eastern part of the State. Rock salt is known to exist below the surface in the south-central part of Kansas, including all of Rice and Kingman Counties, nearly all of Reno County, and parts of Saline, Ellsworth, Barton, McPherson, Stafford, Harvey, Pratt, Sedgwick, Barber, Harper, and Sumner Counties.

The rock-salt beds of Kansas lie in rocks of Permian age, that form the Marion formation. These thin to the eastward beyond Wellington and Little River and die out, possibly without coming near the surface. The salt springs at Geuda Springs, Sumner County, are thought to have their origin in these salt beds. How far the salt and associated beds extend westward is not known. To the north and south the beds are fairly well known through drill records, from Kanopolis, Ellsworth County, on the north, to Anthony, Harper County, on the south; that is, nearly to the Kansas-Oklahoma State line. The beds thin northward. At Anthony they are 404 feet

^a Stose, G. W., work quoted, p. 252.

thick (depth 946 to 1,350 feet); at Kingman, 415 feet thick (depth 665 to 1,080 feet); at Hutchinson, 380 feet thick (depth 430 to 810 feet); at Lyons they are 275 feet thick (depth 793 to 1,068 feet); and at Kanopolis about 250 feet thick (depth 630 to 880 feet). If they maintained this rate of thinning from Hutchinson northward, the salt-bearing beds would disappear before reaching the Nebraska line. Where more than one record is obtainable at a given place, for example, Hutchinson, the exact thickness of the salt-bearing beds and the depth to the topmost bed vary somewhat and may vary considerably from the figures given. The records of the wells at Kanopolis, Lyons, Hutchinson, Kingman, and Anthony contain no reference to appreciable quantities of gypsum below the salt.

LOUISIANA.

RELATIVE IMPORTANCE OF LOUISIANA SALT PRODUCTION.

Louisiana, in 1915, ranked fifth in the quantity but sixth in the value of the salt produced. The output in this State is rock salt.

SITUATION OF DEPOSITS.

Although salt occurs in two distinct parts of the State, namely, the north central and northern part, and the southern part, the more important known deposits and those worked at present are in the southern part of the State close to the Gulf coast.

SALINES OF NORTHERN LOUISIANA.

In the northern part of Louisiana, in the valley of Sabine River, salt springs are known at Negreet, about 1.5 miles above the mouth of Bayou Negreet in Sabine Parish, in the SW. $\frac{1}{4}$ sec. 24, T. 5 N., R. 13 W.; at Stone Coal Bluff Saline, in sec. 33, T. 6 N., R. 13 W.; near Many on the road from Marthaville to Many near Rock Springs Church in the NE. $\frac{1}{4}$ sec. 24, T. 8 N., R. 11 W.

In the valley of Red River are situated the following: Bayou Castor Saline, 5 miles north of Rochelle or about 4 miles above the mouth of Dugdemona River; Catahoula Salt Springs, on Catahoula Lake; Browns Saline, 6 miles west of Tullos or 18 miles southeast of Winnfield on Dugdemona River; near Georgetown at Rochelle, Tullos, and Selma; northwest of Winnfield, Winn Parish, at Cedar Bayou Saline and at Coochie Dome.

Important salines, from which much evaporated salt was obtained during the Civil War and earlier, were known as Drake's, Price's, Rayburn's, and King's, after the names of their respective owners or managers. Bistineau Saline, the largest saline in northern Louisiana, was situated in Lake Bistineau, in secs. 25, 26, 35, and 36, T. 18 N., R. 10 W.

A full account of the more important salines of northern Louisiana is given by Veatch.^a

SALINES OF SOUTHERN LOUISIANA.

The most important salt deposits of the State are on the Five Islands, or Salt Islands as they are sometimes called, namely, Petite Anse, Grande Côte, Belle Isle, Côte Blanche, and Côte Carline. On Averys Island (Petite Anse) and Weeks Island (Grande Côte), rock salt is now being mined on an extensive scale.

Other localities in southern Louisiana where the geologic conditions are similar to those on the Five Islands and where rock salt or salt water, indicating the possible presence of rock salt, has been found in deep drillings, are Anse la Butte, Prairie Mamon, Welsh, Chicot, Vinton, and Hackberry.

Rock salt is mined on Grande Côte (Weeks Island) and Petite Anse (Averys Island).

GRANDE CÔTE (WEEKS ISLAND).

SITUATION.

Grande Côte is situated on the east shore of Weeks Bay, an eastern lobe of Vermilion Bay, in Iberia Parish, and can be reached by the Cypremort branch, from Baldwin, of the Southern Pacific Railroad. Grande Côte is the largest of the Five Islands, which have been described by Veatch,^b though it is barely 2 miles in diameter.

The geology of the beds at the two localities producing salt is described below in some detail, because the occurrence of the salt and the associated gypsum and sulphur is quite different from that of the salt mined elsewhere in the United States. The description below may be considered typical of deposits in most other parts of the Gulf coastal plain of Louisiana and Texas. Fuller discussions of the geology and hypotheses of origin can be found in Bulletin 669 of the United States Geological Survey.^c

OCCURRENCE OF SALT.

At Weeks Island a great mass of rock salt has formed or is forming beneath the superficial beds of unconsolidated sands, clays, and gravels. The topography is not rugged and there are few outcrops. The uppermost bed on the island is a yellow loamy clay, which is exposed in a few places.

^a Veatch, A. C., *The salines of north Louisiana*: Louisiana Geol. Survey Rept., pt. 6, 1902, pp. 47-100.

^b Veatch, A. C., *The Five Islands*: Louisiana Geol. Survey Rept. for 1899, pt. 5, pp. 231-237; *Geology and agriculture*, Louisiana Geol. Survey, Special Rept. No. 3, 1899, p. 209 et seq.

^c Phalen, W. C., *Salt Resources of the United States*: U. S. Geol. Survey Bull. 669. In course of publication.

The records of 44 wells in different parts of the island begin in clay that is 40 to 60 feet thick. Below the clay are sands, ferruginous in places, sand containing chert pebbles, and gray sandy clays, tilted at various angles and striking in different directions. The records show gravel and sand layers that are several hundred feet thick in places. The salt is usually, though not everywhere, overlain with a few feet of clay, for some of the wells show layers of lignite just above the salt.

The salt mass of the island comes closest to surface near the mine, slopes abruptly south and west, less abruptly east, and slightly northward. It occupies the west side of the island and appears to extend a little west of the main ridge. Its form is that of an elongated dome with the north-south diameter longer than the other. The upper surface of the salt mass is known to be irregular and to bear little relation to the surface irregularities of the island. The general shape of the salt mass is regarded by Harris^a as having been formed somewhat as it is at present and not to be due mainly to erosion or subterranean solution.

PETITE ANSE (AVERYS ISLAND).

SITUATION.

Petite Anse or Averys Island is situated in Iberia Parish about 10 miles south-southwest of New Iberia, in T. 13 S., R. 5 E. and 6 E., Louisiana prime meridian.

OCCURRENCE OF SALT.

Veatch and others have described the geology of Petite Anse in considerable detail.^b According to Harris,^c the details given in the earlier descriptions "are of no serious moment in the interpretation of the geology of this and the other salt islands. All beds here seen are admittedly of Quaternary age; none containing anything that can not be referred to inter or post glacial times."

A brownish-yellow loamy soil forms the greater part of the surface. Exposures of gravel are commoner than on the other islands, but seem to be confined chiefly to the southern end of the island. In the northern part are numerous outcrops of a variegated chocolate-yellow or green jointed clay. A bed of lignite was found at the head of Iron Mine Run Hollow, and vertebrate remains of Pleistocene (according to Veatch) mammalia have been found.

^a Harris, G. D., Rock salt: Louisiana Geol. Survey Rept. for 1907, Bull. 7, 1908, pp. 8-9.

^b Veatch, A. C., The Five Islands: Louisiana Geol. Survey Rept. for 1899, pt. 5, pp. 237-253; *Geology and agriculture*, Special Rept. No. 3, Louisiana Geol. Survey, 1899, pp. 243-248.

^c Harris, G. D., Rock salt: Louisiana Geol. Survey Rept. for 1907, Bull. 7, 1908, pp. 14-17.

The records of two wells on the island are given below:

Section of well near sugar house, Petite Anse, La.

Material.	Thickness, feet.	Depth, feet.
Superficial detritus.....	330	.....
Rock salt.....	2,263	2,593
Blue gas sand.....	70	2,663
Salt.....	66	2,729

Section of well at pumping station, Petite Anse, La.

Material. ^a	Thickness, feet.	Depth, feet.
Yellowish clay.....	500	.....
Gravel.....	200	700
Grayish sand.....	2,112	2,612

The upper surface of the salt mass is irregular, as on Weeks Island, and in a few places rises slightly above sea level. Consequently the rock salt lies higher than on Grande Cote or at any other point in the State. Brine springs, well known long before rock salt was actually discovered, attest the elevation of the salt.

TEXAS.

SITUATION OF SALT-PRODUCING AREAS.

Salt in Texas in recent years has come chiefly from Palestine, Anderson County, and Grand Saline, Van Zandt County, in the eastern part of the State. Colorado, Mitchell County, in the western part of the State, was formerly a salt-producing center, but only solar salt now comes from there. The industry of large commercial importance is confined chiefly to the manufacture of evaporated salt, but the salt formed naturally by solar evaporation, in the playas of the western and the lagoons of the southwestern part of the State, is used locally.

Rock salt has been found at the following localities in southeastern Texas, all within the area mapped Pleistocene and Recent by Deussen: ^b Spindletop, Jefferson County; Sour Lake, Hardin County; High Island, Galveston County; Damon Mound, Brazoria County; and Dayton Hill, Liberty County; and there is a single mention of salt in drilling at Batson, Hardin County.^c According to the drillers, 12 feet of salt were found in a well northeast of the center of the Batson field at a depth of 1,007 feet, or 130 feet above the oil rock. In the absence of other mention of salt in this field, this record can not be accepted without reserve. According to Harris,^d streaks of

^a Gravel bed at about 1,500 feet. No salt or water found by the well.

^b Deussen, A., *Geology and underground waters of the southeastern part of the Texas Coastal Plain*: U. S. Geol. Survey Water Supply Paper 335, 1914, Pl. I; see also Fenneman, N. M., *Oil fields of the Texas-Louisiana Gulf Coastal Plain*: U. S. Geol. Survey Bull. 282, 1906, p. 9.

^c Fenneman, N. M., work quoted, p. 53.

^d Harris, G. D., *Rock salt*: Louisiana Geol. Survey Rept. for 1907, Bull. 7, 1908, p. 47.

salt were found at Kisers Hill, Brazoria County. Though no rock salt was struck, salt water in abundance was found at some depth in drilling for oil and gas at Saratoga, Hardin County; Big Hill, Jefferson County; and Humble, Harris County. Without doubt rock salt is known in many other localities.

INDUSTRIAL DEVELOPMENT.

At none of the localities mentioned above has salt ever been mined, and so far as known no serious attempts have been made to obtain it by evaporation of the natural brines. The wells were drilled for gas and oil, and some were enormously productive. Incidentally they have greatly increased our knowledge of the underground formations and the structure of the Gulf Coast domes; without them any well-substantiated theory of the origin of the domes would have been difficult, if not impossible. At some future time the salt may prove of value. Already the sulphur deposits at Freeport, Bryan Heights, Brazoria County, Tex., are being worked in the same manner as those at Sulphur City, Calcasieu Parish, La.

SALINES OF EASTERN TEXAS.

SITUATION.

The principal salines so far described in eastern Texas are: Grand Saline, Van Zandt County; Palestine, Anderson County; Steen Saline and Brooks Saline, Smith County; and a saline 2 miles east of Butler, Freestone County.

Most of the salines are low, flat areas, occupying a depression where brine has been obtained by sinking shallow wells and salt has been made by evaporation. They are surrounded by wooded hills containing white or gray limestone that are in places siliceous and in places glauconitic. Each depression is usually marshy and may hold water during the winter. As summer approaches, the water evaporates, leaving an incrustation of salt.

These salines, like those in northern Louisiana, do not form mounds or islands, but their origin is regarded as being the same as that of the domes near the coast of Texas and Louisiana.

GRAND SALINE.

Grand Saline is situated in northeastern Texas, in Van Zandt County, on the main line of the Texas Pacific Railroad running east from Dallas. The Texas Short Line Railway also enters the town.

The saline itself is a small prairielike sandy plain, in which the sand is strongly impregnated with salt. It is about 1 mile long, east and west, and about one-half mile wide, north and south. The borings made indicate that the beds underlying it are compara-

tively level, though in this general region the strata have been somewhat disturbed.

Six wells have been drilled at Grand Saline, four at the plants of B. W. Carrington & Co., and two at the plant of the Grand Saline Salt Co. In 1912 one well was used at each of the two plants of the Carrington company, and one well at the plant of the Grand Saline Salt Co. The exact thickness of the rock salt in all the wells is not known, but is known to be only local. The salt pinches out a few hundred feet east of the plant of the Grand Saline Salt Co., not even brackish water being obtained there at a depth of 322 feet, whereas in most of the other parts of this region brackish water is obtained comparatively near the surface. West of the town of Grand Saline salt is not encountered at depth and there the town drinking water is procured at rather shallow depths, about 40 feet; a well sunk to 1,000 feet found no salt. No salt has been found at any considerable distance north or south of the town. The salt bed has been developed for only a mile, and it is reported that only one-half mile appears favorable for exploitation.

The sections of two of the wells drilled at Grand Saline are given below.

Log of Lone Star well, Grand Saline, Van Zandt County, Tex.

Material penetrated.	Thickness, feet.	Depth, feet.
Brownish-gray sandy clay.....	26	..
Brown sand.....	8	34
Sand and gravel.....	3	37
Black shaly clay.....	20	57
Lignite.....	3	60
Sandy shaly clay.....	20	80
Sand and water.....	5	85
Sandy clay shale.....	65	150
Sand and water.....	14	164
Hard sand rock.....	6	170
Shale containing pyrites.....	4	174
Blue limestone mixed with streaks of sand and gray limestone, blue forming chief deposit.....	42	216
Hard white sand with a vein of salt water, 5 per cent salt...	14	230
Gypsum.....	5	235
Rock salt; stopped in salt.....	120+	359+

Log of Richardson well, Grand Saline, Van Zandt County, Tex.

Material penetrated.	Thickness, feet.	Depth, feet.
Soil, brownish-black sand.....	3	..
Sandy clay.....	12	15
Gravel and clay.....	5	20
Yellow sand and water.....	6	26
Fine blue clay and gravel.....	2	28
Quicksand with water.....	2	30
Coarse white sand.....	5	35

Log of Richardson well, Grand Saline, Van Zandt County, Tex.—Continued.

Material penetrated.	Thickness, feet.	Depth, feet.
Blue gray merging into bluish-black dirt with pyrite and broken limestone.....	48	83
Hard gray limestone.....	3	86
Sandy shaly clay (slate?).....	17	103
Blue clay with pyrite.....	20	123
Shale(?).....	9	132
Shale with iron pyrite.....	5	137
Sandy shale with pyrite.....	12	149
Sandstone with pyrite.....	14	163
Hard blue limestone.....	25	188
Hard gray limestone.....	3.5	191.5
Quicksand.....	2.5	194
Alternate strata of salt and limestone.....	18	212
Rock salt.....	300	512
Bluish-gray sand.....	2	514
Black sand with water; not penetrated.....	6	520

PALESTINE.

Palestine, the county seat of Anderson County, is situated in the south central part of the county on the International and Great Northern, and on the Texas State Railroads. It is in the far eastern part of the State and is about equidistant from Red River, the north line of the State, and the Gulf coast.

West of the town the land slopes toward Trinity River, and 6 miles to the southwest of the town is the saline itself, which occupies a flat measuring about 1 mile by half a mile. Around the edge of the flat incrustations of salt are observable. The surface soil is a dark or lead-colored clay, as at Grand Saline.

STEEN SALINE.

The Steen Saline is situated in the northern part of Smith County, 5 miles east of Lindale and 14 miles north of Tyler, on Saline Creek, just north of the forks. The saline proper is a small prairie 1 or 2 miles in length and one-half to three-fourths of a mile wide. The surface of the saline is covered with salt incrustations and is composed of black or grayish-black clays.

Large quantities of salt were made at this saline during the Civil War by digging shallow wells and evaporating the brine in huge kettles and boilers. According to report, as many as 20 furnaces were run at times, turning out 12,000 sacks (size unknown) of salt daily. It took 190 gallons of water to make 1 bushel of salt.^a

BROOKS SALINE.

The Brooks Saline is situated in the southwestern part of Smith County, about 17 miles southwest of Tyler. It is about 2½ miles

^a Buckley, S. B., Report of assistant State geologist: Texas Geol. and Agri. Survey First Ann. Rept., 1874, p. 126.

long and one-half to three-quarters of a mile wide. Its surface consists of blue and black clays, and around its edges is a yellow laminated clay.

OCCURRENCES OF SALT IN WESTERN TEXAS.

SALT BASIN OF TRANS-PECOS REGION.

One of the salt basins of western Texas, known as Salt Basin, has been described by Richardson.^a It is situated in the Trans-Pecos region, and the part studied lies north of the Texas Pacific Railroad in El Paso, but near Culberson County. It is west of the Guadalupe-Delaware Mountains and east of the Sierra Diablo. The basin, which trends northwest and southeast, has a total length of 150 miles, and the area described by Richardson includes 70 miles of this linear extent. The area studied is 8 to 20 miles wide, with an average width of 15 miles, and constitutes a typical inclosed basin.

The salt deposit is on the west side of the basin, about 15 miles southwest of El Capitan Peak and slightly more than 50 miles north of Van Horn. It occupies a slight depression, being one of several "salt lakes" in this part of the basin. The layer of salt that covers the surface is said to attain in places a thickness of 4 to 6 inches, but the measurements made by Richardson showed only 1 inch of commercially valuable salt. The salt is grayish white, coarsely crystalline to granular, and deliquescent. Wind-blown impurities occasionally cover its surface. During the dusty dry season the salt becomes impure, but after a rain, and especially in localities where the surface salt has been recently removed, beautiful hopper-shaped crystals are formed. Analyses^b of these salt crystals and of a typical specimen of salt from the basin are given in the following table:

Analyses of salt from Salt Basin, El Paso County, Tex.

[S. H. Worrell, analyst.]		
Constituent.	Hopper-shaped crystals.	Typical specimen of salt deposit.
Chlorine (Cl).....	59.5	59.0
Sodium (Na).....	38.6	38.3
Calcium (Ca).....	.1	Trace.
Magnesium (Mg).....	.2	Trace.
Sulphate radicle (SO ₄).....	1.2	1.0
Potassium (K).....		.0
Silica (SiO ₂).....		.6
Alumina (Al ₂ O ₃).....		.6
Iron (Fe).....		Trace.
Water.....	1.0	.....
	100.6	99.5

^a Richardson, G. B., Salt, gypsum, and petroleum in Trans-Pecos, Texas: U. S. Geol. Survey Bull. 260, 1905, pp. 573-585.

^b Richardson, G. B., work quoted, pp. 579-580.

COLORADO CITY.

Salt is obtained by evaporation at Colorado City, Mitchell County, in the western part of the State. Where the Pennsylvanian and Permian beds are developed in this region numerous salt springs and wells are found. At Colorado City rock salt was found at a depth of 850 feet in drilling for water, and 140 feet of rock salt was passed through in the next 250 feet. The water in the wells rose to within about 150 feet of the surface and could not be exhausted by pumping. There has been little or no change in the character of the water since the operating company began work. The wells are cased to the first bed of rock salt at 850 feet. Fresh water was found above and below the beds of salt.

OTHER OCCURRENCES OF SALT.

During the past few years several wells have been drilled in the northwestern part of Texas in what is sometimes termed the Pan-Handle. The presence of much salt, gypsum or anhydrite, and in a few wells, small quantities of potash salts, has been revealed. The names and locations of some of the wells drilled are as follows:

S. M. Swenson & Sons well, Spur, Dickens County.
Glenario well, Glenario, Deaf Smith County.
Adrian Oil & Gas Co. well, near Adrian, Oldham County.
Adrian Townsite Co. well, near Adrian, Oldham County.
Boden well, Potter County.
Miller Ranch well, Randall County.
McLean well, Gray County.
Four wells in or near Childress, Childress County.
Post City well, Garza County.
Justiceburg well, Garza County.
Snyder well, Scurry County.
Scoggin well, near west boundary of Kent County.
Upland well, Upton County.
Buena Vista well, Pecos County.
Deep well, northwest of Toyah, Reeves County.

In the north and west central parts of Texas, for example at Graham, Young County, salt has been obtained from shallow wells. The wells at Gordon, and other places in Palo Pinto County, the flowing well near Waldrip, McCulloch County, and those near San Angelo, Tom Green County, yield salty water. Along the southwestern coast, lagoons or salt lakes have yielded and can still yield a large yearly production of salt.

OKLAHOMA.

RELATIVE IMPORTANCE OF SALT INDUSTRY.

The salt industry in Oklahoma is of local importance only. During the past few years salt in the State has been produced on a small

scale near Ferguson, Blaine County, in the western part of the State, and near Salton and Vinson, Harmon County, in the extreme southwestern part.

SALT PLAINS.

SITUATION.

Salt-water wells and springs occur in eastern and western Oklahoma. In the eastern part of the State most of the water is only a little salty; in the western part the water is so salt in places that the terms "salt springs" or "salt plains" are in common usage.

The regions where the springs are situated are known as salt plains generally, and according to a recent report of the Oklahoma geological survey, 10 of these are well known, situated as follows: Two along the Cimarron River between Woods, Woodward, and Harper Counties; 2 in northwestern Harmon County; 1 each in Alfalfa, Blaine, and Beckham Counties; and 3 on Sandy Creek, south of Eldorado, Jackson County. A geological progress map^a of the State shows the surficial rocks in these regions as belonging in the Permian. Although all the salt springs of western Oklahoma issue from and probably originate in the "Red Beds," they do not all issue from the same geologic horizon.

OREGON.

No salt has been prepared in Oregon in recent years, but it is said to have been prepared from brine from springs in Willamette and Umpqua Valleys, as well as from brine from other places.^b Springs in Jackson County are also reported to have produced salt. Beds of rock salt have been reported near the base of Mount Jefferson, in Cascade Range. Alkali, Abert, and Summer Lakes contain salt in conjunction with other salines like soda and potash salts, and work for soda has been conducted in a small way around Alkali Lake.

IDAHO AND WYOMING.

Salt has been produced in Bannock and Bear Lake Counties, Idaho, in recent years. In recent years the industry has been confined to the vicinity of Stump Creek and Tygee Valley, Bannock County, southeastern Idaho. The headquarters of most of the operators have been at Auburn, Wyo. The salt industry in this part of Idaho is of slight importance, a considerable part of the production being cattle salt. The salt has been obtained from brine springs, but beds of rock salt occur below the springs.

^a Oklahoma Geol. Survey Bull. 5, 1911.

^b Brown, J. R., *Resources of the Pacific Slope*, San Francisco, 1899, pp. 255-256.

NEVADA.**RELATIVE IMPORTANCE OF NEVADA SALT INDUSTRY.**

The salt industry in Nevada has never been of more than local importance. Scattered salt deposits have been worked from time to time to supply local demand, but most of the enterprises yet started have been on a small scale and have been operated only spasmodically.

During recent years salt has come from Sand Springs, White Plains, Leete, and Parran, Churchill County; from the Silver Springs playa, Esmeralda County; and from the Buffalo Salt Works, Sheepshead, Washoe County. Most of the salt is obtained by solar evaporation, and the finer grades like table and dairy salt and common fine salt are prepared from the solar product by different refining processes. Other known deposits are at Dixie Salt Marsh, Churchill County; Railroad Valley, Nye County; and west of Diamond Range, in Eureka and Elko Counties. Deposits of present or prospective importance are situated along Virgin River in the southeastern part of the State. In fact, numerous saline valleys are widely distributed in that part of Nevada included within the Great Basin.

NEW MEXICO.**RELATIVE IMPORTANCE OF SALT OUTPUT.**

Though the commercial output of salt in New Mexico is and has been small, there is no scarcity of salt. The saline or salt-bearing lakes of this State are to be considered among its important future resources, and though little or no salt is exported, a considerable quantity of the crude product is used for salting stock. The salt thus used is gathered usually by scraping up the deposit formed about salt springs or as a thin layer on the surface of the salines or playas during the dry season. The principal lake basin deposits are those in Estancia Valley.

SITUATION OF DEPOSITS.

A small production of salt has been reported in recent years from Estancia, Torrance County. The salt basin is in the central part of the county, near the geographic center of the State. Salt is also found in flats among the gypsum ridges in what are known as the White Sand Plains of the Tularosa Basin, in parts of Dona Ana, Socorro, and Otero Counties.

The Zuni salt deposits of New Mexico are in the northwestern part of Socorro County, about 80 miles south of Gallup, on the main line of the Santa Fe Railroad and about the same distance west of Magdalena, on a branch line of the same system. The deposits have supplied Indians and Mexicans for centuries, and at present the salt is hauled to surrounding ranches. A small colony of Mexicans collect the product in a crude manner.



A. SALT MINE OF L. JACOBS, $2\frac{1}{2}$ MILES NORTHWEST OF REDMOND, SEVIER COUNTY, UTAH. UNIQUE OCCURRENCE OF SALT AT SURFACE.



B. SALT MINE OF INLAND CRYSTAL SALT CO. IN SANPETE COUNTY, UTAH, 1 MILE NORTH OF L. JACOBS'S MINE. UNIQUE OCCURRENCE OF SALT AT SURFACE.



There are many salt springs in New Mexico, but no salt is obtained from them except for limited local use. One large spring is on Rio Salada, 30 miles northwest of Albuquerque, another is 20 miles west of Belen, and a third is at the end of Malpais in Tularosa Valley, 48 miles northwest of Alamogordo. There are scores of smaller springs in the State.

The Red Beds, which underlie the Pecos Valley and Staked Plains in Eddy, Chaves, and Roosevelt Counties, contain many thick and extensive beds of salt, but are far beneath the surface. Information regarding them is derived from records of scattered borings for water or oil. These salt deposits are 300 to 500 feet thick, in heavy beds separated by layers of clay or sand, and in part of the area they lie only a few hundred feet below the surface. The 2,600-foot boring at Carlsbad in this area penetrated many thick salt beds, and they have been reached by borings east of Artesia and Roswell, as well as by numerous deep holes in the Staked Plains region in western Texas, some of them not far east of the New Mexico line.

ARIZONA.

No salt is produced at present on a commercial scale in Arizona. Common salt, as well as other chemically precipitated salts, has been deposited from the river water in the valley of Salt River with clastic sediments; and, though the salt does not form deposits geologically important, it is of great importance from its effect on the river water. The salt is thought to come from large salt springs in the upper reaches of the river. The water from these springs has been described as a weak brine.

The salt deposits in Virgin River Valley have been mentioned under Nevada. Blake^a refers to rock salt disseminated in the beds in the valley of Verde River, Yavapai County, in the south-central part of the State.

UTAH.

RELATIVE IMPORTANCE OF UTAH SALT INDUSTRY.

The nonmetallic mineral resources of Utah, like those of other western States, are still so comparatively unexplored that descriptions of almost any such deposits are necessarily incomplete. This holds true of saline deposits, particularly those of rock salt and underground brine, and in addition to those named below many others will doubtless be found.

The main salt industry in Utah is on the east shore of Great Salt Lake, at Saltair, not far from Salt Lake City, and is important and flourishing. Some salt is produced also at Garfield. All the salt now and heretofore made along the lake shore is from solar evaporation of the water of the lake.

^a Blake, W. P., Mineralogical notes: Am. Jour. Sci., 3d ser., vol. 39, p. 44, 1890.

SALT-PRODUCING LOCALITIES.

The most important occurrences of salt in the State are as brine in the waters of Great Salt Lake; as rock salt in Sevier Valley, near Salina, Redmond, and Gunnison, both in Sevier and Sanpete Counties; east of Nephi, Juab County, where brine also is found; near Clear Lake in the eastern part of Millard County; and Salt Lake Desert, Tooele County. Salt is being or has been produced at all the localities mentioned. Two mines near Redmond are shown in Plate I.

GREAT SALT LAKE.

Production has from time to time been reported from along the shores of Great Salt Lake, in Boxelder, Weber, Davis, and Salt Lake Counties, but with the exception of the works of the Inland Crystal Salt Co., at Saltair, on the shore of the lake 15 miles west of Salt Lake City, the operations are small and are carried on somewhat sporadically. Small amounts of salt are reported to have been gathered recently at Promontory Point, Boxelder County; at Withee, Weber County, 15 miles west of Ogden; at Syracuse, Davis County; and at Garfield, Salt Lake County. The evaporation processes employed along the lake shore to make salt are generally similar. The methods of the Inland Crystal Salt Co. are typical, as the operations at the plant of that company are by far the most elaborate.

Among other salt deposits in Utah that have come to the attention of the writer are those at Little Salt Lake, Iron County, and south of Beaver in Beaver County; and the salt marshes in Snake Valley in the western part of Millard County.

CALIFORNIA.**RELATIVE IMPORTANCE OF SALT PRODUCTION.**

California ranked sixth among the States in quantity and fifth in value of the salt produced in 1915. The State has had this same relative rank during the past three years.

GENERAL OCCURRENCE OF SALT.

Salt occurs in California in practically every known form. In solution it is found in the brines of salt springs, salt lakes or marshes, and saline streams, of which certain tributaries of Salinas River, in San Luis Obispo County, are examples. In Inyo, San Bernardino, and other counties in the Great Basin many springs and streams are slightly brackish or salty. Many of the so-called alkaline or salt lakes contain water only during certain seasons of the year. During dry seasons they are covered with a crust of salt, which in many places is several inches thick. The Great Basin region contains many marshes, playas, or lakes, where salt may be collected by simply

scraping the crust. In addition to the rock salt resulting from the evaporation of saline solutions, salt undoubtedly will be found either disseminated or in segregated beds or masses buried in Quaternary lake deposits. Such deposits have originated in intermittent periods of desiccation. Rock salt occurs in a few deposits in the earlier lake beds, of which that on the north side of the Avawatz Mountains is a splendid example.

PRODUCTION OF SALT FROM SEA WATER.

More than 97 per cent of the salt made in California is from the solar evaporation of sea water along the coast. Most of the solar salt and the finer grades produced from it come from the shores of San Francisco Bay, in Alameda and San Mateo Counties. The headquarters of the salt industry are at Alvarado, Newark, Mount Eden, Russell, and Baumberg, formerly Arffs, in Alameda County, on the east shore of San Francisco Bay, and at Redwood City and San Mateo, in San Mateo County. In the southern part of the State solar salt is made at Ostend Station, near Long Beach, Los Angeles County, and on the San Diego Bay, San Diego County. The general methods of making this salt and preparing it for market are described on pages 40 to 49.

One of the main reasons for the bulk of California salt coming from along the coast is that the principal centers of population are situated there. The market is at hand and the cost of transportation is reduced to a minimum. Lack of a market and cost of transportation are the main reasons why many important deposits in the interior of the State have hitherto remained unworked.

PRODUCING LOCALITIES.

Besides the salt obtained from sea water by solar evaporation along the coast, salt has been made in small quantity in recent years at inland points as follows: Tramway (Keeler post office), Inyo County; Ward, San Bernardino County; near Saltus (Amboy post office), San Bernardino County; near Cedarville, Modoc County; at Caneda, a few miles southwest of Randsburg, and at Saltdale, Kern County.

DESCRIPTION OF OCCURRENCES.

COLUSA COUNTY.

About 25 years ago the manufacture of salt was begun at certain brine springs near Sites, Colusa County, and has continued more or less intermittently at that locality ever since, though the latest reports are that no more salt is being gathered. A number of other salt springs are known in different parts of Colusa County.

INYO COUNTY.^a

Inyo County is situated in the eastern part of California and is wholly within the boundaries of the Great Basin. In this county are included Owens Lake, Death Valley, the Saline Valley Salt Marsh, and the dried valleys of numerous other salt lakes, among which are Indian Wells Valley, Salt Wells Valley, and Panamint Valley. Though Searles Lake lies within San Bernardino County for the most part, for convenience it is here treated as being within Inyo County. Searles Lake, in former geologic time, formed a link in an ancient drainage system in which the members, beginning with the most elevated, were Owens Lake, Indian Wells Valley, Salt Wells Valley, Searles Lake, Panamint Valley, and Death Valley.

The salts found in Owens Lake, the waters of which are a dense brine, include common salt, soda, borax, and potash and other salts. According to calculation, the waters of the lake contain 160,000,000 short tons of anhydrous salts, a large part of which is sodium chloride.

The most distinctive feature of the Desert Basin, which included formerly Searles Lake, Indian Wells Valley, and Salt Wells Valley, is now Searles Lake. The immense sheet of solid white salts in its bottom is unique in this country for the variety of its saline minerals. The salt crust occupies a roughly circular area believed to be 11 or 12 square miles in extent. The depth of the salt, as shown by drillings, is fairly uniform, being reported to range from 60 feet to more than 100 feet, and to average 70 to 75 feet in the main part of the deposit. The salt deposit is in effect a consolidated mass crystallized from an evaporating mother liquor in which the salts are still immersed. The lake is one of the most promising sources of domestic potash salts.

Much saline material is accumulated on and beneath the floor of Death Valley. A central area of crusted salt lies in the lowest part of the valley and extends many miles north and south. Analyses of the saline content of the floor of the valley indicate an approximate content of 95 per cent common salt.

Salt deposits occupy the lowest part of Saline Valley, which is without outlet. Smooth, white salt deposits, about 1 square mile in areal extent, are surrounded by broken and tilted salt crust blocks with sharp, craggy surface; the salt from the smooth crust in the lowest part of the valley contains 98.52 per cent of sodium chloride, indicating that it is of high grade for a natural product.

Salt has been found at other places in Inyo County, as at Tecopa, Confidence Spring in South Death Valley, and in the canyon of Armagosa River.

^a These notes have been abstracted from a contribution by H. S. Gale: U. S. Geological Survey Bulletin 600, previously mentioned.

KERN COUNTY.

In Kern County, Cameron Lake, Kane Lake, and Castac Lake are ephemeral lakes crusted with salt during the dry season. Some salt has been obtained from Kane Lake in recent years.

MONO COUNTY.

Mono Lake, near the Nevada line, contains dense alkaline water. Sodium chloride or common salt constitutes nearly 35 per cent of the total solids in the lake water. Calculations based on the area of the lake and its average depth indicate that it contains nearly 90,000,000 tons of common salt, and more than 10,000,000 tons of potassium chloride.

SAN BERNARDINO COUNTY.

Saltus.—Salt was produced as late as 1913 near Saltus (Amboy post office), a station on the Santa Fe Railroad in the southeastern part of San Bernardino County. The salt occurs in the bottom of an old lake bed in the form of rock-salt layers, under approximately 5 feet of overburden.

Armagosa River.—Armagosa River, for a short part of its course, flows through San Bernardino County, but the main part of the river is in Inyo County, to the northward, and within Armagosa Valley, Nye County, Nev. The term "river" is somewhat misleading, because its waters appear and disappear, being absorbed by the porous beds over and through which they flow. Though the river water is potable near its source, increasingly large quantities of various salines render it bitter, as the name Armagosa ("bitter" in Spanish) signifies. In the lower courses of the river in San Bernardino County, where the water comes to the surface, these salines are deposited as white crusts and deposits of salt and borate minerals are formed. These crusts have been removed and marketed. Some of them by natural re-solution and recrystallization have been rendered nearly pure.

Avawatz Mountains.—Rock salt outcrops on the north side of the Avawatz Mountains, in San Bernardino County, in a zone between 4 and 5 miles long, and probably underlies a large area. The salt is a member of a saline series that in upward order consists essentially of celestite, gypsum, and salt, the entire saline series being underlain and overlain with lake beds.

Where the salt has been worked its purity has increased with depth. It is massively crystalline, and is generally brownish near the surface from the presence of reddish-brown clay that owes its color to iron oxide. Some chemical analyses show the salt to be more than 98 per cent pure.

Danby.—Salt has been mined 30 miles southeast of Danby, a station on the Santa Fe Railroad, in the southeastern part of San Bernardino County, in a dry lake known as Danby Lake. Here the salt lies in two beds, each from a few inches to several feet thick, separated by a thick layer of clay and protected by a layer of sand and dust. The salt bed has been opened over an area of many acres, which forms only a small part of the deposits.

Mohave River and Sink.—The Mohave River rises in the San Bernardino Mountains, flows north and northeast through Barstow and Daggett, and more nearly east to Soda Lake, the sink of Mohave River, otherwise known as Mohave Sink. The river is about 100 miles long, and the Santa Fe and the San Pedro, Los Angeles & Salt Lake Railroads follow it for miles. Except during flood season there is little surface flow. The river waters are saline, and there are saline efflorescences all along their course. The water carries principally salt, sodium carbonate, and sodium sulphate, with small quantities of potash salts, borates, bicarbonates, silica, etc. It is reported that some salt has been made by diverting water from the surrounding hills to that part of the lake where desired. The salt is absorbed and the brine conveyed to vats and there evaporated. Only coarse salt has been marketed from the region.

Other localities.—Other localities in San Bernardino County where salt exists are (1) Bitter Springs at the southeastern end of Bitter Lake in T. 13 N., R. 5 E., San Bernardino meridian; (2) Daggett; (3) Owl Springs, which are located in the northwestern part of the county, between the west end of Avawatz Mountains and the east flank of Owl Mountains; (4) Salt Springs, on the south fork of Armagosa River, at the southeast end of Death Valley; (5) in the vicinity of Saratoga Springs, 14 miles to the northwest of Salt Springs; (6) Valley Springs, about 8 miles northwest of Saratoga Springs, the water being so salty as to be undrinkable; (7) Willards Lake. This lake is in the northwestern part of the county in Ts. 30 and 31 S., R. 42 E., Mount Diablo meridian. The beds of the lake, like those of most lakes in this region, are impregnated with salt, and the shore is marked with white crusts.

SAN LUIS OBISPO COUNTY.

Soda or Salt Lake, in Carriso Plain, contains important deposits of sodium sulphate, with which small quantities of ordinary salt are associated. Carriso Plain is near the northeastern boundary of San Bernardino County, and the lake is in T. 31 S., Rs. 19 and 20 E. The saline deposits are estimated to cover an area of approximately 3,000 acres. The exploitation of the deposits for sodium sulphate was discontinued a few years ago.

OTHER LOCALITIES.^a

Other localities in the State where salt has been reported to be found in small quantities are as follows:

Calaveras County.—There are salt springs on the Mokelumne River, 6 miles south of Silver Lake.

Contra Costa County.—Alhambra Mineral Springs.

Humboldt County.—Eureka Springs.

Lake County.—Allen Spring, Borax Lake, Lake Hachinhama, Hot Borate Spring, Clear Lake, Howard Spring, and Siegler Spring.

Los Angeles County.—According to Bailey^b there are large salt springs 14 miles from the city of Los Angeles, the exact location not being given.

Modoc County.—Near Cedarville.

Napa County.—Aetna Springs, Calistoga Springs, White Sulphur Springs.

Placer County.—Salt Springs are reported near the Clipper Cap Iron Mine.

San Benito County.—Anderson's Springs.

Santa Clara County.—Pacific Congress Springs, Alum Spring, Azule Spring, Blodgett Spring, near Gilroy, New Alamaden Spring.

Shasta County.—Salt was made at one time on Salt or Stinking Creek, 12 miles east of Redding.

Siskiyou County.—Strong brine is reported to flow from a well, 675 feet deep, near Yreka.

Solano County.—Tolenas Springs.

Sonoma County.—Santa Rosa Spring, Skagg's Springs, White Sulphur Spring.

Tehama County.—Tuscan Springs, Little Salt Creek.

^a Doubtless this list will now be found incomplete, and the author will welcome communications that will add to its accuracy.

^b Bailey, G. F., The saline deposits of California: Cal. State Min. Bureau Bull. 24, May, 1902, p. 136.

SALT-MAKING PROCESSES.

CLASSIFICATION.

The processes of salt making in the United States are of two kinds: (1) The mining of rock salt and its purification and separation into marketable sizes, and (2) the production of salt by evaporation from brines, bitterns, and other solutions containing it. The processes employed in the manufacture of salt by evaporation may be classified as follows:

1. Solar evaporation.
2. Direct-heat evaporation:
 - (a) In open kettles.
 - (b) In open pans.
3. Steam evaporation:
 - (a) In jacketed kettles.
 - (b) In grainers.
4. Vacuum-pan evaporation.

SOLAR EVAPORATION.

WHERE PROCESS IS USED.

In the eastern States solar evaporation is not general because of the climate, and is confined, so far as the writer knows, to New York State. In the western States, and particularly in California and Utah, the process is extensively used.

SOLAR EVAPORATION AT SYRACUSE, N. Y.^a

COMMERCIAL STATUS OF INDUSTRY.

The manufacture of salt by solar evaporation began in New York in the vicinity of Syracuse, Onondaga County, in 1789, and the process is limited to Syracuse and vicinity, where it has survived from early days. Though only a small part of the evaporated salt manufactured in New York is now made by the solar process, before 1880, when the beds of rock salt in the western part of the State began to be utilized, Onondaga County supplied the entire output of the State in rock (coarse) salt. The greater part of the total now returned for the county represents the salt in brine consumed in the manufacture of soda. The solar salt produced is mainly coarse salt, and is used for practically the same purposes as

^a In the preparation of this section the author has made free use of the works of F. E. Englehardt, *The manufacture of salt in the State of New York*: New York State Mus. Bull. 11. 1893, pp. 28-44, and T. M. Chatard, *Salt-making processes in the United States*: U. S. Geol. Survey Seventh Ann. Rept., 1888, pp. 497-527.

rock salt. It is marketed through the Onondaga Coarse Salt Association.

The wells are on lands once included in the Onondaga Indian Reservation, and until recently the State supplied the brine to individual plants, exacting a small tax on the product to cover costs of pumping and supervision. However, in 1908, the lands and wells were sold to the Onondaga Pipe Line Co. and the Mutual Pipe Line Co. of Syracuse. This transfer definitely terminated the long connection of the State with salt making.

Solar salt is made from a natural brine—the only instance of its use in New York. The process, of course, is carried on only during the spring, summer, and fall months, usually from the middle of March to the middle of November, depending on the weather.

The increased value of the enormous acreage covered by the plant and the higher charges for labor, lumber, taxes, and insurance have appreciably decreased the returns from solar evaporation in the State.

ORIGINAL METHOD.

Formerly solar salt was made in shallow wooden vats or "covers," provided with light movable roofs running on rollers. (See Pl. II.) During the evaporating season the roofs were moved to one side, but were replaced during rainy weather and at the end of the salt-making season. The natural brine containing 17 to 20 per cent sodium chloride (68° to 80° salometer) flowed successively to three sets of vats or "rooms" known, respectively, as deep rooms, lime rooms, and salt rooms, about two-thirds of the space in a salt yard being given to salt rooms. The rooms were generally 18 feet wide and their length, or the length of a "string" (series) of them, depended on the length of the salt yard, which was often as much as 400 or 500 feet. The lime and salt rooms were 6 inches and the deep rooms 12 to 14 inches deep. The movable covers of the rooms were built in 16-foot sections, thus covering an area of 288 square feet. In the larger and longer yards the floor of each salt room was 6 or 8 inches higher than that of the next below. The advantages of this arrangement were that the fresher pickle could be regularly separated by gravity from the older, and that after the pickle in the lowest room had been removed during harvesting, fresher pickle could be drawn into the room to remove adhering chloride of magnesium and crystals of gypsum from part of the salt.

When the brine was first pumped into the deep rooms, which served mainly for storage, it was usually clear, but with the escape of gases (mostly carbon dioxide) ferrous carbonate separated, which on oxidation to the hydrated ferric oxide settled out as a yellow mud, leaving the brine again clear. The brine then flowed into the lime rooms, where evaporation continued until the brine became saturated and salt crystals began to separate. During this process,

particularly near the time of complete saturation, gypsum began to separate. The term "lime room," which is somewhat misleading, as no lime was used in the process, was probably applied because of gypsum separating in the room. The brine, then known as "pickle," flowed to the salt rooms, where the salt and the remainder of the gypsum separated, sufficient pickle being added from the lime room from time to time to keep the salt crystals well covered. The salt crystals were finally gathered from the floor of the salt room after the mother liquor had been drawn off.

IMPROVED METHOD.

Great improvements have been made in the original method of solar evaporation, one of the greatest being the use of "aprons" in place of the deep rooms and the lime rooms, whereby the evaporating surface and the yield of salt per cover (288 square feet) have been greatly increased. The aprons are shallow wooden troughs 3 inches deep, 15 to 20 feet wide, and of various lengths. (See Pl. II.) They are generally erected over the deep rooms and serve as roofs as well as storerooms for the saturated brines of the deep rooms. They are built on piles or posts and are sloped 1 inch in 100 feet, so that the liquid in them flows toward two sets of holes provided with wooden plugs. One set of holes communicates with the deep rooms and the other with the waste drain. The brine run into the aprons often becomes saturated in one good drying day. It is then discharged into the deep room below and its place is taken by fresh brine. When rain is expected the plugs over the deep rooms are removed and the brine, flowing from the aprons, is thus saved from dilution. These plugs are then replaced and the other set is removed, the rain being thus allowed to flow to waste. The partly concentrated brine is returned to the aprons by pumps when clear weather returns. The process is carried on usually from the middle of March to the middle of November, the exact period depending on the weather.

The brine is thus concentrated and purified while it is being transported to the "covers." The great length and width of the aprons, the shallowness of the brine, and its complete exposure to the sun, air, and wind greatly facilitate purification and evaporation; also they permit the use of the entire number of "covers" for salt making, instead of one-third of the total cover area being occupied by lime rooms and deep rooms. This improvement greatly increased the production of solar salt per cover and, as considerable capital is invested in covers, the economy of the process is obvious.

RECOVERY OF SEA SALT IN CALIFORNIA.

PRODUCTION CENTERS.

More than 97 per cent of the output of salt in California originates from the solar evaporation of sea water along the coast. The largest



A. HARVESTING SALT PRODUCED BY SOLAR EVAPORATION AT SYRACUSE, N. Y.



B. SALT VATS WITH ROOFS REMOVED; SOLAR EVAPORATION PROCESS, SYRACUSE, N. Y.



plants are along the east and west shores of San Francisco Bay, in Alameda and San Mateo Counties, respectively. In Alameda County the centers of production are near Alvarado, Mount Eden, Russell, Baumberg (formerly Arffs), and Newark; in San Mateo County solar salt is produced a short distance south of San Mateo, near Redwood City. Other solar plants are at Ostend Station, near Long Beach, Los Angeles County, and on San Diego Bay, San Diego County. At all these places the operations are conducted in somewhat similar manner, although differing considerably in details. Also the nomenclature of the processes varies somewhat. The following general description of the processes is based on observations at representative plants in different localities.

SALT-MAKING SEASON.

The concentration of the water in San Francisco Bay varies with the season of the year and other factors. The water of the bay is diluted somewhat by fresh water from San Joaquin and Sacramento Rivers, the dilution being increased after winters of heavy snow, which does not completely melt until summer is well advanced. Brine is taken into the salt ponds around San Francisco Bay from the middle of May to the middle of October, but the strongest brines are obtained after the 1st of July, as the dry season lengthens and the inflow of fresh water from the rivers appreciably declines. Generally the salt-making season is over by September 15, as the dry season lasts usually from May to September. However, a season as long as 210 days without rain has been known along San Francisco Bay.

The mean average date when crystallization of salt began around San Francisco Bay was May 1 in 1908, May 13 in 1909, May 3 in 1910, May 25 in 1911, and April 18 in 1912. The early date in 1912 was because of few late rains that year. Records are closed, that is, evaporation readings are stopped, November 1, after which the days are so short, the water is so cold, and the weather so uncertain that there is practically no evaporation.

During the summer season of 1911, which may be taken for purposes of illustration, the evaporation and rainfall observed at one plant were as follows:

Rainfall and evaporation, in inches, season of 1911, San Francisco Bay, Cal.

Month.	Rainfall.	Evapora- tion.
	<i>Inches.</i>	<i>Inches.</i>
April.....	1.36	3.38
May.....	1.14	5.31
June.....	.67	6.62
July.....	.00	7.81
August.....	.00	7.81
September.....	.00	4.94
October.....	.77	2.94

The water from the bay or ocean is not taken into the works continuously but during two to six days a month, when the tides are highest, usually at the period of new moon. During high tide water is run into the ponds one and one-half to three hours. At some plants where a slough^a runs through the intake pond salt water may be taken in at any time or every day. Thus at Long Beach the sea water runs into a ditch at every high tide; that is, twice a day. Salt water may therefore be pumped continuously from this ditch into the plant.

The salt-making season is naturally longer in southern California than near San Francisco. At San Diego it lasts about seven months, from May to November, and salt water also may be taken in continuously by draining the tide ponds, into which sea water enters during every tide above a given height.

STRENGTH OF BRINE.

The average density of sea water is 1.027, corresponding to a salinity of 3.72 per cent regarded as pure salt. Three samples of bay water collected as they ran into plants on the shores of San Francisco Bay and on San Diego Bay gave results as follows:

Density and salinity of sea water used in salt making, California.

Source.	Date of collection.	Density.	Specific gravity. ^a	Percentage of salt. ^b
San Francisco Bay at Mount Eden.....	1912. Oct. 5	* B. 3.53	1.025	3.44
San Francisco Bay at Alvarado.....	8	3.12	1.022	3.34
San Diego Bay.....	17	4.10	1.029	4.00
Sea water.....			1.027	3.72

^a Specific gravities were taken at 22° C., but are referred to water at 15° C.

^b Assumed to be pure NaCl, which is not exactly correct.

The normal salt water entering the salt plants along San Francisco Bay is less strongly concentrated than ordinary sea water, whereas the bay water near San Diego is more strongly saturated. The difference in density between waters from San Francisco Bay and those from San Diego Bay is caused partly by the fact that farther south the warm dry season lasts much longer and consequently evaporation is more intense, and partly by the fact that streams of fresh water flow into San Francisco Bay.

SALT PONDS.

Salt is made in ponds which are designated according to the operations taking place in them; thus there are the storage, intake, receiving, or tide ponds into which the salt water is received from the bay, the concentrating ponds, and the crystallizing ponds (Pls. III, IV,

^a The term slough is applied to an artificial canal, ditch, channel, or inlet.

and V). All ponds between the tide ponds and the crystallizing ponds are called secondary ponds by some operators; technically they may be termed pickling ponds. The term lime ponds is sometimes applied to those in which the bulk of the gypsum crystallizes.

The sea water enters the works, generally through a slough, into the intake, receiving, storage, or tide pond, which is provided with large flood gates that automatically open when the water can run in and close as the tide ebbs. In the intake pond the salt water remains and evaporates a variable length of time before the next salt water is taken in, and goes through the different ponds, gradually getting more concentrated, until it finally reaches the crystallizing ponds. It is run into these to a depth of about 6 inches when it has reached a strength of about 25° B., or when crystals of salt have begun to form. At some plants when the pickle in the salt ponds has reached a strength of 29° B., the bittern with some salt still in it is run into other ponds, where it evaporates until a concentration of 32° B. is reached. As it is generally believed that all the salt is then out of the mother liquor, it is allowed to go to waste, but in view of its composition as given on pp. 47 and 48, recovery of magnesia and potash salts ought seemingly to be profitable if undertaken on a comprehensive scale. At some plants part of the mother liquor is utilized, as will be seen by referring to p. 46, and indications are that the future will see a general utilization of what for years has been a waste product.

Specific gravity of bitterns from crystallizing ponds of California.

Locality.	Density at 22° C.	Specific gravity. ^a
	° B.	
Oliver plant, Mount Eden.....	32.50	1.288
Leslie Salt Co., San Mateo.....	29.60	1.256
California Salt Co., Alvarado.....	27.21	1.231
Long Beach Salt Co., Long Beach.....	28.00	1.239
Do.....	28.60	1.245
Western Salt Co., San Diego Bay.....	27.50	1.234

^a Specific gravities were determined at 22° C. by R. K. Bailey with a Westphal balance, but they are referred to water at 15° C.

Pond area is one of the dominant features of the industry. The total acreage of ponds at a few plants is as small as 500 acres, but at others it is reported to be more than 2,000 acres. The ratio of the area of crystallizing ponds to that of the whole system at two large plants is 1 to 10. The older works have more ground available for crystallizing beds because the ground becomes more thoroughly salted and consequently harder and less pervious with continued use.

The ponds have mud floors and are separated from one another by low embankments or dikes that differ greatly in width and height. The dikes may be as much as 3 feet above the level of the marsh and

1 or 2 feet above the level of the brine. Some are very narrow, but others, especially some of the outside dikes, are so wide and well built that they serve as roadways. Low narrow dikes are not considered good by all the salt makers, as they require frequent repair to meet the constant wash of the waves. However, if the levees are too high they may hinder the evaporating action of the wind, but there is not much wind at San Diego. The dikes between the ponds were formerly flanked with sod, but this practice is being abandoned.

METHODS OF PUMPING.

The brine around San Francisco Bay is raised partly by Archimedean screws propelled by windmills (Pl. VI) and partly by paddle wheels, some plants having as many as 40 windmills. Some plants use gasoline engines as auxiliary power, especially in the fall after the trade winds die down and in August when the trade winds slacken or blow intermittently. Electric power is also coming into use.

The windmills face northwest, from which direction the trade winds come. The pumps are generally placed so as to pump from the intake pond into a pond high enough to allow the brine to move by gravity (Pl. IV, A), the flow from one pond to the next being controlled by small gates. Windmills or other means may, however, be used for lifting in parts of the system where utilization of gravity is inexpedient (Pl. VI).

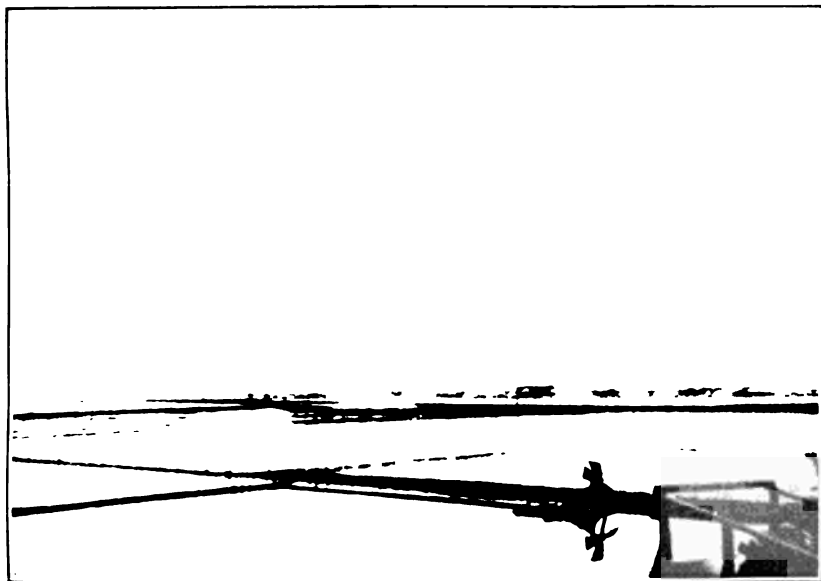
HARVESTING.

The crop of salt is usually sold before July of the following season. Enough salt is thereafter gathered from time to time to supply the current demand until September, when harvesting (Pls. VII and VIII) is pushed as vigorously as possible. At many plants the first salt is lifted about the first of June and the operation is continued until about the first of January or February of the following year if the crop is big and labor is rather scarce; ordinarily, however, harvesting is finished by December.

Usually the salt deposit is first harvested to within 2 inches of the mud floor; then the remaining lower grade is harvested separately and is sold for making ice cream and for stock. The salt is shoveled into tram cars holding about a ton. The salt thus lifted has a pinkish hue, and the mother liquors are likewise pinkish. A small locomotive propelled by gasoline or electricity then hauls 6 or 8 cars to the mill or to the salt piles or stacks. Small stacks are made at some plants, and at others one huge stack is made near the mill (Pl. IX, A). The latter method is doubtless more economical, for it reduces both the surface exposed to solution by rain and also that which has to be broken in subsequent utilization of the salt. The latter consideration is important, for the surface hardens so firmly that it can be broken only with the greatest difficulty; indeed, the cost of breaking a par-



A. VIEW OF CRYSTALLIZING PONDS, SHOWING ONE FIELD READY TO BE HARVESTED.
LESLIE SALT CO., SAN MATEO, CAL.



B. SALT PONDS AND SALT PILES AT PLANT OF UNION PACIFIC SALT CO., SAN FRANCISCO
BAY, CAL.



A. GRAVITY METHOD OF RUNNING BRINE FROM ONE POND TO ANOTHER. OLIVER SALT CO. PLANT, MOUNT EDEN, CAL.



B. SALT GARDENS, OLIVER SALT PLANT, MOUNT EDEN, CAL.

ticularly old crust on a small stack is sometimes more than the salt is worth and some old small stacks have been discarded for that reason. The salt in some stock piles hardens so firmly that cross-cut saws are used to cut it into 4-foot lengths, which are pried apart and crushed in the subsequent milling.

At some mills the salt is dumped through a hopper to a screw conveyor, which carries it to a bucket elevator that lifts it to the main stack. Not every plant can use this method, for the ground has to be very firm to accommodate the enormous tonnage of one main stack—a condition not common in regions of marshy land. Sinking of the ground may cause loss of an appreciable part of the product. At one mill the filling sank 1 foot a year for 20 years.

At one plant the salt is shoveled by laborers, a line of whom extend the width of a pond, onto an endless belt 20 inches wide, running on rollers and operated by a gasoline engine, which conveys the salt to one side of the pond. As the salt leaves the belt it is washed with a spray of salt water from the bay (Pl. IX, *B*). Then it is dragged up a perforated copper screen by an endless drag chain provided with forks to break up the larger lumps. During the ascent the salt is again washed with bay water. The salt is then raised to the stacks by a pan elevator so run that the open mouths of the pan are reversed to enable the excess of wash water to drain. The main belt, which conveys the salt from the pond, is kept perfectly clean by a washing device. The salt from the outside stock piles is brought to the mill as needed in 5-ton cars. This method has many advantages. As soon as a given area of salt has been removed from the crystallizing ponds the entire layout is moved forward on tracks, and the salt pile may thus be extended the length of the pond. The washing of the salt is also performed when the adhering bittern is most readily and completely removed.

At Long Beach the salt is shoveled from the stock pile into small cars, which are carried by a rope tram to a crusher in which the salt is ground. A bucket conveyor takes the salt to a bin in an ordinary freight car, which is hauled by a motor to the mill when the bin is full.

At San Diego the salt in the crystallizing pond has to be broken with a pickax before it can be shoveled, the greater firmness of the crystals as compared with those of the salt along San Francisco Bay possibly being due to quicker crystallization. It is customary to begin harvesting as soon as the bittern is drained from the crystallizing ponds, as the salt is easier to pick, shovel, and wash at this stage than at any other.

The yield during a season varies from year to year, being governed by the weather and other factors. A thickness of 5 or 6 inches of salt a season would be a fair approximation for the region around

San Francisco Bay, but in the southern part of the State, owing to the longer and dryer season, it would be much larger. At San Diego, for example, an average harvest is 6 inches of salt, and two such harvests can be gathered each season.

MILLING.

Because of the nature of the processes employed in the manufacture of solar salt, and more particularly because of the differences between them and those employed in other parts of the United States, the first stages of the milling operations in California differ from corresponding operations elsewhere. When the salt is lifted from the crystallizing ponds it is contaminated with considerable adhering pickle or bittern and dirt of various kinds. If it is not to be used at once it may undergo a preliminary washing, after which it is conveyed to the stacks. If it is to be used immediately it is carried to the mill and there washed to free it from adhering impurities.

Washing is accomplished in various ways. The salt may be dumped into a hopper and a current of hot brine from the pickling pond poured over it. The brine is bay water concentrated to complete saturation, and therefore for a concentrated solution it contains the least amount of mother-liquor salts and consequently dissolves a minimum amount of salt during the washing. An elevator lifts the salt from the hopper, the salt draining in the meanwhile. Then the salt passes between rolls which crush it into "half-ground salt" or "three-quarters ground salt." Next it goes to vats filled with artificial brine that is made from salt and fresh water and consequently contains no mother-liquor salts. On removal from these vats the salt is stacked in heaps to drain. The coarse salt is then sacked for one branch of the trade. If it is to be subjected to further refining the salt goes from the vats to a centrifugal machine, by which adhering water is removed. It is then conveyed to driers, which are long revolving cylinders containing steam coils and provided with fans that pump warm air through. From the driers the salt goes again to the rolls to be crushed and finally to the sifters to be graded according to fineness. It is then ready to be sacked for the trade.

Operations at different plants differ greatly in details. At some plants the salt in the stock piles is redissolved and the finer grades are made by the vacuum-pan process; then the manipulation of the salt at the mill may be quite different from that just outlined.

UTILIZATION OF BITTERN.

The bittern from the crystallizing ponds has never been saved at some of the plants, and at most of them it is even now entirely wasted. Since the value of potash salts has been realized, some operators have had in mind recovery of the potash in the bitterns, but few have

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A. SALT CRYSTALLIZATION IN CRYSTALLIZING PONDS, LESLIE SALT CO., SAN MATEO, CAL.



B. CRYSTALLIZING PONDS AT LESLIE PLANT, SAN MATEO, CAL., SHOWING METHOD OF TRANSPORTING RAILS FOR LAYING NEW TRACKS.



A. SLOUGH AND WINDMILLS AT OLIVER SALT PLANT, MOUNT EDEN, CAL.



B. WINDMILL, OLIVER SALT PLANT, MOUNT EDEN, CAL.

evolved definite methods for obtaining this by-product. It is reported that the Leslie Salt Refining Co., in conjunction with the Whitney Chemical Co., has begun to manufacture epsom salts, magnesium chloride, and potash salts from residual bitterns.^a

Edward B. Durham,^b of Berkeley, Cal., and doubtless many others, have also experimented with the residual bitterns from the manufacture of salt along San Francisco Bay and southern California. Durham has separated the magnesium from these bitterns in the form of magnesium carbonate, making use of sal soda. By this process the potash salts are left in the filtrate from the magnesium carbonate.

As the price of magnesium chloride has been high on the Pacific coast during the war, separation of this chloride as well as the sulphate from these bitterns has also been considered. The artificial carnallite produced in the process would also be utilized.

At one plant a small part of the bittern is refined for medicinal use; at another it has been used in the manufacture of "wood stone" and magnesium oxychloride cement. The latter substance is an excellent nonconductor of electricity and has been utilized in the manufacture of switchboards. It is understood that bittern has been used by the Santa Fe Railroad to lay the dust along its roadbed, but this use is not economical because the bittern has to be applied frequently.

In the table following are given analyses of the bittern obtained in connection with the manufacture of salt on the California coast.

Analyses of bitterns from sea water.

[Samples collected by E. E. Free in 1912; R. F. Gardiner, analyst.]

RADICALS IN GRAMS PER LITER.

Constituent.	Sample No.							
	1	2	3	4	5	6	7	8
K.....	8.2	13.4	13.2	14.6	21.5	35.0	11.8	0.7
Na.....	80.0	75.8	38.8	27.7	9.1	93.6	60.1	61.0
Ca.....	1.2	2.2	.6	.5	1.0	.2	1.1	Trace.
Mg.....	24.0	23.4	50.6	62.7	79.4	8.6	43.9	24.8
Cl.....	179.2	176.6	179.4	183.3	220.1	180.4	190.8	148.5
SO ₄	30.0	31.4	53.6	74.2	62.0	29.0	55.8	34.1
Br.....	3.0	3.0	3.0	3.0	2.0	2.0	2.8	.....
	325.6	325.8	339.2	366.0	395.1	348.8	366.3	269.1

CONVENTIONAL COMBINATIONS IN GRAMS PER LITER.

KCl.....	15.6	25.5	25.2	27.8	41.0	66.7	22.5	1.3
NaCl.....	203.0	192.7	98.6	70.4	23.1	240.0	152.7	160.4
MgCl ₂	65.0	63.8	144.5	171.1	250.6	4.2	117.5	63.5
CaSO ₄	4.0	7.4	2.3	1.7	3.3	.6	3.7	Trace.
MgSO ₄	33.9	32.8	65.0	91.5	75.3	35.8	66.7	42.7
MgBr ₂	3.4	3.4	3.4	3.4	2.3	2.3	3.2	.....
	324.9	325.6	339.0	365.9	395.6	349.6	366.3	267.9

^a American Fertilizer, New potash factory: vol. 45, Sept. 30, 1916, p. 48.

^b Personal communication.

^c Grams per kilogram.

Analyses of bitterns from sea water—Continued.

RADICALS IN PERCENTAGE OF ANHYDROUS RESIDUE.

Constituent.	Sample No.							
	1	2	3	4	5	6	7	α 8
K.....	2.51	4.11	3.80	3.99	5.44	10.03	3.22	0.25
Na.....	24.57	23.27	11.45	7.57	2.30	26.83	16.41	22.68
Ca.....	.37	.63	.18	.14	.26	.06	.30	.00
Mg.....	7.33	7.18	14.92	17.13	20.09	2.47	11.98	9.21
Cl.....	55.03	54.20	52.88	50.07	55.71	51.72	52.10	55.19
SO ₄	9.22	9.64	15.80	20.28	15.69	8.32	15.23	12.67
Br.....	.92	.92	.88	.82	.51	.57	.76	.....
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

CONVENTIONAL COMBINATIONS IN PERCENTAGE OF ANHYDROUS RESIDUE.

KCl.....	4.80	7.83	7.43	7.60	10.37	19.07	6.14	0.48
NaCl.....	62.48	59.19	20.09	19.24	5.84	68.66	41.69	59.88
MgCl ₂	20.00	19.60	42.62	46.77	63.35	1.20	32.09	23.70
CaSO ₄	1.23	2.27	.68	.46	.83	.17	1.01	.00
MgSO ₄	10.44	10.07	19.18	25.00	19.03	10.24	18.20	15.94
MgBr ₂	1.05	1.04	1.00	.93	.58	.66	.87	.....
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

α Grams per kilogram.

SOURCE OF SAMPLES.

1. Leslie Salt Refining Works, San Mateo, Cal. Representative sample taken near northwest corner of mother-liquor pond.
2. Leslie Salt Refining Works, San Mateo, Cal. From southeast corner of mother-liquor pond.
3. Leslie Salt Refining Works, San Mateo, Cal. From salt-making pond, in which salt had been forming during the summer.
4. Oliver Salt Works, Mount Eden, Cal. From slop pond, representing 5 years' accumulation.
5. Oliver Salt Works, Mount Eden, Cal. Mother liquor that had been subjected to special treatment.
6. California Salt Co., Alvarado, Cal. From slop pond, representing 3 years' accumulation, though considerable quantities had been abstracted and small quantities of other waste liquors had been added.
7. Pioneer Salt Co., San Francisco, Cal. One year's accumulation.
8. Long Beach Salt Co., Long Beach, Cal. Abnormally concentrated bittern from an outlying tank, 1912, R. K. Bailey, analyst.

NOTES ON SAMPLES.

The analyses of the bitterns resulting from the extraction of salt from sea water on the California coast are remarkable for the indicated proportion of magnesium salts, both the chloride and the sulphate, and also for the rather large proportion of potassium. Calcium is present in very small proportions, probably in the form of sulphate. Bromine is present in relatively small proportions. The relatively large content of potassium makes it probable that these bitterns might be evaporated and utilized in the manufacture of low-grade fertilizer material, such as manure salts, hartsalz, and kainite.



A. LOADING SALT ON SMALL CARS TO BE CARRIED TO THE PLANT FOR REFINING, AT OLIVER SALT PLANT, MOUNT EDEN, CAL.



B. HARVESTING SALT IN THE HARVESTING POND OF THE LONG BEACH SALT CO., LONG BEACH, CAL.



PANORAMIC VIEW SHOWING SALT PONDS DURING HARVESTING PROCESS, LONG BEACH SALT CO., LONG BEACH, CAL.

SALT PRODUCTION

Salt has been used for many centuries on the shores of rivers and seas. The first salt settlements were made in the Mediterranean Sea. The first salt works were made in the Mediterranean Sea. The first salt works were made in the Mediterranean Sea. The first salt works were made in the Mediterranean Sea.

The chief interest in the study of salt is the analysis of the water. The chief interest in the study of salt is the analysis of the water. The chief interest in the study of salt is the analysis of the water. The chief interest in the study of salt is the analysis of the water. The chief interest in the study of salt is the analysis of the water.

The following are the chief sources of salt in the world. The following are the chief sources of salt in the world. The following are the chief sources of salt in the world. The following are the chief sources of salt in the world. The following are the chief sources of salt in the world.

Cl.....
Br.....
S.....
C.....
L.....
Na.....
K.....
Ca.....
Mg.....
Fe.....

Solubility, per cent

a. Chloride of Na
b. Chloride of K
c. Magnesium



PANORAMIC VIEW SHOWING SALT PONDS DURING HARVESTING PROCESS, LONG BEACH SALT CO., LONG BEACH, CAL.

SALT PRODUCTION AT GREAT SALT LAKE, UTAH.

PRODUCTION CENTERS.

Salt has been made by solar evaporation for many years along the shores of Great Salt Lake, the industry dating in fact from the early settlement of the region. A small amount of salt is reported as having been made recently at Promontory Point, Box Elder County; Withee, Weber County; Syracuse, Davis County; and at Garfield, Salt Lake County. The most elaborate operations ever attempted along the lake shore are conducted at the plant of the Inland Crystal Salt Co., near Saltair, 15 miles west of Salt Lake City. The process of obtaining salt near Saltair is described below.

CHARACTER OF BRINE.

The chief differences in the results of various chemists who have analyzed the water of Great Salt Lake are in the degree, but not in the character of the salinity. It is to be expected that the concentration would change with changes in dilution from local sources. The water of Great Salt Lake, which is the brine utilized, is similar in composition to sea water, though its concentration is four to seven times that of sea water, and consequently it furnishes a much stronger brine for salt making. (See analyses below.) A sample from the lake north of Lucin Cut-Off, near Withee Junction, Utah, collected by the writer in 1912, had a salinity of 13.35 per cent, according to a test by R. K. Bailey.

The following analyses tabulated by Clarke ^a show the composition of the water. Other analyses are given by Gilbert.^b

Analyses of water from Great Salt Lake.

Constituent.	Sample No.								
	1	2	3	4	5	6	7	8	9
Cl.....	55.99	56.21	55.57	56.54	55.69	55.25	55.11	53.72	55.48
Br.....	Trace.				Trace.	Trace.			
SO ₄	6.57	6.89	6.86	5.97	6.53	6.73	6.66	5.95	6.68
CO ₂		.07							.09
Li.....	Trace.				.01	Trace.			
Na.....	33.15	33.45	33.17	33.39	32.92	34.65	32.97	32.81	33.17
K.....	1.60	(7)	1.59	1.08	1.70	2.64	3.13	4.99	1.66
Ca.....	.17	.20	.21	.42	1.05	.16	.17	.31	.16
Mg.....	2.52	3.18	2.60	2.60	2.10	.57	1.96	2.22	2.76
Fe ₂ O ₃ , Al ₂ O ₃ , SiO ₂					.01				
Salinity, per cent.....	100.00 14.994	100.00 13.790	100.00 15.671	100.00 19.558	100.00 23.036	100.00 27.72	100.00 22.99	100.00 17.68	100.00 20.349

^a Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 491, 1911, p. 144, and Bull. 616, 1916, p. 155.

^b Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 1890, pp. 253-254.

^c More correctly, 230.355 grams per liter.

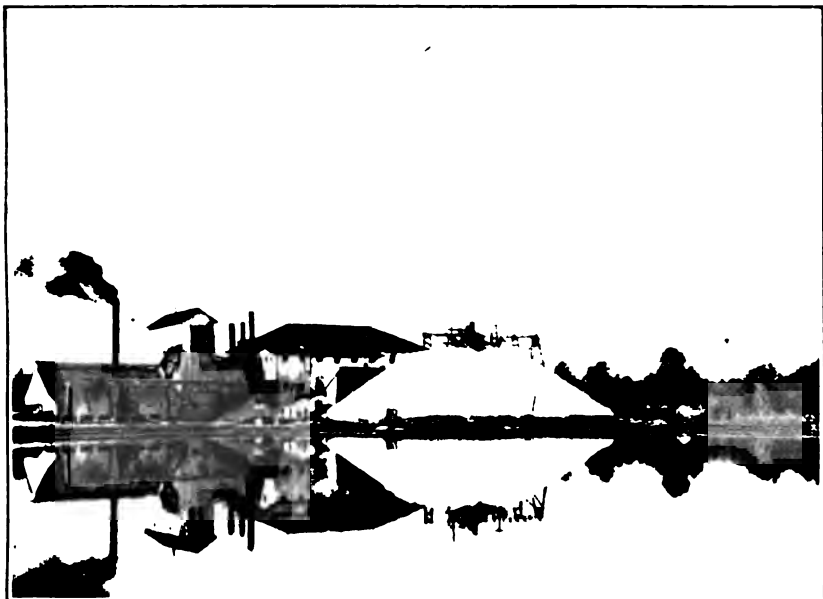
DATA REGARDING SAMPLES.

1. Analyzed by O. D. Allen, Rept. U. S. Geol. Expl. 40th Par., vol. 2, 1877, p. 433. Water collected in 1869. A trace of boric acid is also reported in addition to the substances named in the table. Allen also gives analyses of a saline soil from a mud flat near Great Salt Lake. It contained 16.40 per cent of soluble matter much like that of the lake water.
2. Analyzed by Charles Smart. Cited in Resources and Attractions of the Tertiary of Utah, Omaha, 1879. Analyses made in 1877.
3. Analyzed by E. von Cochenhausen, for C. Ochsénus. Zeitschr. Deutsch. geol. Gesell., vol. 34, 1882, p. 359. Sample collected by Ochsénus, April 16, 1879. Ochsénus also gives an analysis of the salt manufactured from the water of Great Salt Lake.
4. Analyzed by J. E. Talmage, Science, vol. 14, 1889, p. 455. Collected in 1889. An analysis of a sample taken in 1885 is also given.
5. Analyzed by E. Waller, School of Mines Quart., vol. 14, 1892, p. 57. A trace of boric acid is also reported.
6. Analyzed by W. Blum. Collected in 1904. Recalculated to 100 per cent. Reported by Talmage in Scottish Geog. Mag., vol. 20, 1904, p. 424. An earlier paper by Talmage on the lake is in the same journal, vol. 17, 1901, p. 617.
7. Analyzed by W. C. Ebaugh and K. Williams, Chem. Ztg., vol. 32, 1908, p. 409. Collected in October, 1907.
8. Analyzed by W. Macfarlane, Science, vol. 32, 1910, p. 568. Collected in February, 1910. A number of other analyses, complete or incomplete, are cited in this paper by Ebaugh and Macfarlane.
9. Analyzed by R. K. Bailey, in the laboratory of the U. S. Geological Survey. Sample collected by H. S. Gale, October 24, 1913.

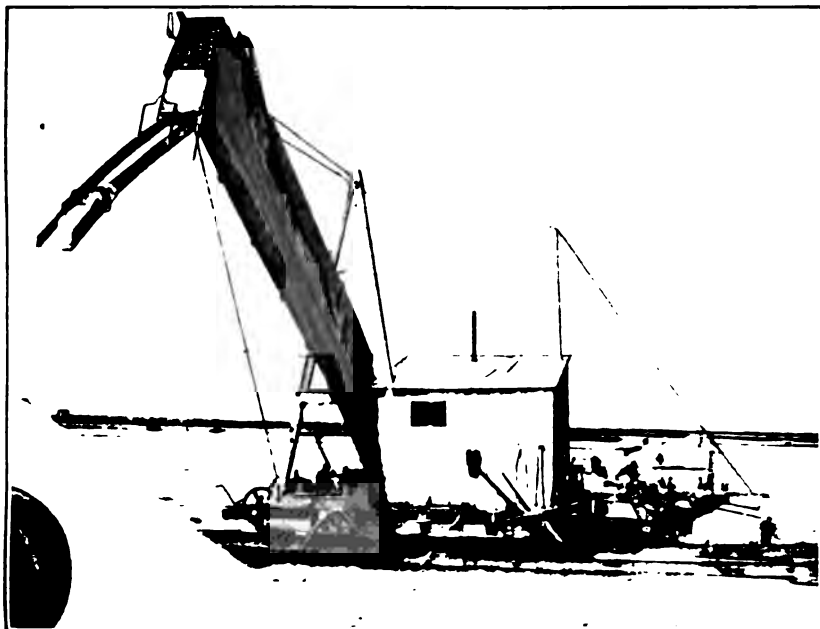
Sodium is higher but calcium and magnesium, especially the former, are distinctly lower in the lake water than in sea water. Carbonates are almost entirely absent from the lake water but are present in ocean water. Calcium carbonate is precipitated on the shore of the lake in the form of oolitic sand. Gilbert^a states that the quantity of sodium chloride in the water of the lake is about 400,000,000 tons and that the amount of sodium sulphate is about 30,000,000 tons.

As the lake is shallow its volume is greatly affected by small changes in its level. As the total salinity (salt content) may be considered fairly constant, the strength of the brines is affected only by the changes in level. Observations were made in 1850, when the lake was at its lowest observed state; in 1873, when the lake was at its highest stage; in 1869, when it was at an intermediate stage; and in 1885 and 1889. From a comparison of the extreme results it appears that the salinity was decreased 39 per cent by a rise of 10.5 feet, which represents on the assumed basis of no change in total saline content an increase of 73 per cent in the volume of water in the lake. The saline matter presumably has been derived chiefly from the fresh-water rivers flowing into it and from the brackish springs along its edges. Whether these springs derive their saline matter from extraneous sources or from beds originally deposited in the Bonneville basin is unknown. If the latter is true the springs

^a Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1. 1890, p. 253.



A. LESLIE SALT PLANT, SAN MATEO, CAL.



B. METHOD OF MECHANICALLY LIFTING SALT FROM THE SALT PONDS AT CALIFORNIA SALT PLANT, ALVARADO, ALAMEDA COUNTY, CAL.

could hardly be regarded as contributing an original quota of saline material. Gilbert ^a says that it must be regarded as an open question whether the existing lake and its characteristic brine dates from the end of the Bonneville overflow (Pleistocene) or from a subsequent epoch of extreme aridity.

SALT MAKING AT SALTAIR.

The brine is pumped from the lake into a flume, in which it is carried about 3 miles to the ponds for concentration and crystallization. The ponds are designated from the processes taking place in them as settling ponds, stock or evaporating ponds, and crystallizing or harvesting ponds. They are separated from one another by clay embankments 2 feet wide and 22 inches high, held in place by boards set on edge. Pumping begins in April and continues until the first of September except during storms. Evaporation goes on approximately at the rate of pumping, which is about 5,000 gallons a minute, for 16 hours a day from the middle of June to the middle of September, the season of greatest dryness and hence of maximum evaporation. Pumping is regulated to maintain a constant level in the ponds.

The brine from the lake goes first to the settling ponds, in which it is allowed to remain five or six days to remove all suspended matter. The settling ponds cover about 75 acres. From the settling ponds the brine goes to the stock ponds, which cover an area of about 1 square mile, and it remains in them until concentration reaches complete saturation and salt is ready to deposit, the length of time depending on the weather. The brine then goes to the harvesting ponds. During the summer of 1912, when the writer visited the region, 30 days elapsed between the beginning of pumping operations and the time the brine reached the harvesting ponds. The brine is conducted from one pond to another by gravity, the flow being controlled by small gates.

In the harvesting or crystallizing ponds, as the name suggests, evaporation is permitted till all salt separates. To insure a clean product an under layer or salt floor is allowed to crystallize each year unless it is left over from the operations of the preceding year, as in 1912. When it is left over, as happens when the crop is greater than the market demands, the salt in it becomes more or less dirty and is sold for feeding to stock. The salt that is marketed comes from the upper layer, the plane of demarcation between it and the floor being known as the "split."

The bittern formed in the harvesting ponds is drawn off twice, once at the middle of the season and once at its end. In this way the salt is freed from the bulk of magnesium salts and sodium sulphate. Care must be exercised to draw off the bittern before cold weather

^a Gilbert, G. K., *Work quoted*, p. 258.

in order to avoid crystallization of sodium sulphate, which is said to take place when the water reaches a temperature of 20° F.^a Talmage^b believes the critical temperature of the separation to be within a few degrees of the freezing point of fresh water, or approximately 35° F.

Some careful experiments recently carried out in the chemical laboratory of the United States Geological Survey by R. C. Wells have shown that Great Salt Lake water having a specific gravity of 1.145, becomes saturated with respect to mirabilite, $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$, at 1° C., or 34° F.

When the bittern has been drawn off the last time and the salt is ready to be lifted, ordinary plows drawn by horses (Pl. X, A) loosen it. Then it is stacked by means of scrapers, wheelbarrows, or hand cars run on tracks in large piles beside the railroad (Pl. X, B). The salt is conveyed in cars from the stacks to the company's mill where it is further refined. Part of the yield is sold without further treatment.

The average crop is about 3 inches of salt, though other writers who have described the industry give figures as high as 6 inches.^c The minimum crop is about 2 and the maximum about 4 inches, though a crop of nearly 5 inches has been obtained.

PRINCIPAL METHODS OF EVAPORATING SALT.

At present the most important methods of manufacturing evaporated salt comprise direct heat and steam evaporation. The vacuum-pan method is included among those in which steam evaporation is employed, although it is sometimes classified separately. Of the various methods of evaporation that have been employed in the past and are now being used, three may be considered, namely, evaporation in open pans, in grainers, and in different forms of vacuum pans. On the following pages these three methods are described in general terms with illustrations of the different steps in the processes from different localities. Detailed descriptions are given of the processes actually used in different States. In this way the reader may obtain an idea of the process without having to go into the details; and anyone who is interested in the details practiced in any particular State can confine his attention to the description given under that State.

DIRECT-HEAT EVAPORATION.

EVAPORATION IN OPEN KETTLES.

HISTORY.

The open-kettle process is the original method employed at Syracuse, N. Y., and so far as known it has been used in recent years

^a Gilbert, G. K., *Lake Bonneville*: U. S. Geol. Survey Mon. 1, 1890, p. 253.

^b Talmage, J. E., *The Great Salt Lake—present and past*: The Desert News, 1900, p. 80.

^c Talmage, J. E., place quoted; Barbour, P. E., *The Utah solar salt industry*: Eng. and Min. Jour., vol. 92, 1911, pp. 74-75.



A. PLOWING SALT IN HARVESTING PONDS, PREPARATORY TO HARVESTING THE SALT. ORDINARY FARM PLOWS ARE USED. INLAND CRYSTAL SALT CO., SALT AIR, NEAR SALT LAKE CITY, UTAH.



B. LOADING SALT ONTO CAR FOR SHIPMENT TO REFINING PLANT. INLAND CRYSTAL SALT CO., SALT AIR, NEAR SALT LAKE CITY, UTAH.



C. ROYAL SALT PLANT AND REFUSE SALT PILE, KANOPOLIS, ELLSWORTH COUNTY, KANS.

only on the Onondaga Salt Reservation. A gradual evolution has taken place from small beginnings dating back to the earliest history of the salt-making industry at Syracuse, when the first salt was made simply by boiling with an open fire. Next a kettle set in an arch of mason work was used, then followed kettles in pairs, and later four kettles combined in a "block," a term still used in the largest salt-making plants in New York and Michigan. The number of kettles in a block gradually increased until 30, 40, 60, and even 100 were placed in a line or in two parallel lines and suspended in two parallel flues or arches terminating in a chimney. As enlarging a block necessitated more fire, the kettles nearest the fire were too intensely heated and arches had to be built under the first 12 or 15 kettles to protect them, a procedure not conducive to economy of fuel. Next, artificial draft was furnished by a pressure blower. Owing to inherent difficulties in the process, it has been estimated that with a given quantity of good fuel not more than two-thirds as much water is evaporated in a kettle block as can be evaporated in a properly constructed boiler. For this and other reasons the kettle system could not compete with other methods and has gradually been abandoned. Originally there were more than 300 salt blocks in the vicinity of Syracuse, but none is now in active use.

CONSTRUCTION OF APPARATUS.

The kettles employed in the process were approximately 2 feet in depth and 4 feet in diameter. Those nearest the fire had a capacity of 150 gallons and those farthest away a capacity of 100 gallons. The kettles were thickest at their bottoms, tapering from $1\frac{1}{2}$ inches to three-fourths inch in thickness at the rim. The lugs or pins on which the kettles were suspended were 5 inches long and $1\frac{1}{2}$ inches in diameter and were placed opposite each other 4 or 5 inches below the rim.

The arches or flues in which the row or rows of kettles were set were inclosed in two side walls, between which when two parallel rows of kettles were used was a central wall built of stone and lined with ordinary brick, except from the front to the fifteenth kettle where fire brick was used. Beyond the grate the fire-brick arches were built with air spaces between them, which increased in size with distance from the grates, thus allowing the heated gases to pass through the spaces without directly striking the bottoms of the kettles. The flues decreased in depth toward the chimney, becoming only 6 or 8 inches deep under the last kettle. The kettles were so hung with their rims against one another, masonry preventing escape of heat between the walls and the kettle rims, that the surface exposed to the heated gases passing through the arches was as large as possible. The slanting of the sides and central walls and the decreasing depth of flue toward the chimney facilitated this.

A wooden conduit lengthwise of the block and a few inches above the central wall had plugs that permitted ready flow of brine to the different kettles by gravity from outside cisterns.

METHODS OF OPERATION.

The brine employed in the manufacture of "boiled" or "common fine" salt, as it was usually called, was of the same strength as that used in the solar process. Before the brine went to the kettles a little quicklime slaked with brine to form a thin milk was stirred in for the purpose of removing the iron, which was quickly precipitated as a reddish-yellow sludge of hydrated ferric oxide. After about 24 hours of settling the brine was a clear bluish-green solution.

When the salt making began a wrought-iron pan so shaped as to fit snugly to the sides was placed in each kettle. The handle of the pan was near the center of the kettle for ease of insertion and withdrawal. It was known as the "bittern pan," and was used to collect the calcium sulphate which began to separate as the brine approached complete saturation. It was withdrawn several times from the kettle before the salt began to separate, and the sediment which collected in it was thrown away. When salt began to form the pan was finally withdrawn. When enough salt had separated it was "drawn" or removed to baskets laid across the rim of the kettle and washed with a mixture of the pickle left in the kettle plus fresh brine added after the removal of the first batch of salt. The basket remained usually until the kettle had been "drawn" a second time, when the contents of the basket were dumped into the bins. The steam from the kettles also acted as an efficient agent in making the salt, as when it rose into the salt in the baskets above it dissolved adhering calcium and magnesium chlorides.

In spite of the efforts to remove calcium sulphate there was a constant tendency for an incrustation to form; this layer thickened more rapidly in the kettles nearer the fire than in those farther away, because salt was made more rapidly in the former than in the latter. The kettles near the fire were drawn every 4 or 5 hours, and those farthest away were drawn only once in 24 or 36 hours. As the layer of calcium sulphate in the front kettles became thicker, it materially retarded evaporation because of its being an exceedingly poor conductor of heat. After five or six days, therefore, the salt was drawn from the front kettles together with nearly all the pickle. Fresh water was added, and after boiling for some time the layer of calcium sulphate was partly dissolved and loosened so as to be easily removed. When the kettles nearest the chimney were ready to be cleaned those nearest the fire had again reached a condition in which recleaning was necessary; the fires were, therefore, allowed to go out, accumulated salt was removed from the kettles, the mother liquor was dipped

out into the gutter, and the kettles were cleaned. Brine was then added and another run was begun, a considerable quantity of salt having formed in the meantime in the front kettles from the heat remaining in the arches below them. This salt was much coarser than the boiled salt and was kept separate. The time consumed in a run varied from 10 days to two weeks. The salt remained in storage for two weeks to drain, after which it was ready for the market.

The quality of the products and the efficiency of the process depended on the weather, on the strength and quality of the raw brine, on the character and condition of the fuel, and on a multitude of other conditions of minor-importance.

EVAPORATION IN OPEN PANS.

The open-pan process of making salt is employed in New York, Michigan, Kansas, and on a minor scale in the Sevier Valley, Utah.

PRELIMINARY TREATMENT OF THE BRINE.^a

The brine is pumped from the wells into settling tanks where it remains a day or so exposed to the air to allow the escape of gases, such as hydrogen sulphide, and the precipitation of as much of the iron compounds as possible. Then a thin emulsion of lime is added and the solution is agitated, either mechanically or by hand, or is aerated with a current of air to insure thorough mixing. Through the chemical action of the lime any iron compounds present which would discolor the product are precipitated and removed. A day or so after the addition of the lime, soda ash may be added, particularly if the salt is intended for table or dairy use. After the addition of the soda ash, the brine is allowed to stand for several days to become perfectly clear, but the length of time allowed for settling depends largely on trade conditions. In the Saginaw Valley, Mich., where bromine and calcium chloride are made as well as salt, the bromine may first be removed by electrolysis. The brine may or may not be preheated before it goes to the pans themselves.

PAN CONSTRUCTION AND MANIPULATION.

The shallow open pans employed in making salt are illustrated in figure 1. They are made of riveted wrought-iron plates, $\frac{1}{8}$ to $\frac{1}{4}$ inch thick, and have flaring sides. In New York some that are in use have two compartments separated by a wood or metal partition. These compartments are known as the front and the back pans, the former being nearer the fire. In New York and Kansas the pans are usually about 100 to 115 feet long, 23 to 30 feet wide, and 12 to 18 inches deep, the back or preheating pan being shorter than the front

^a For further details, see "Grainger Process," p. 61.

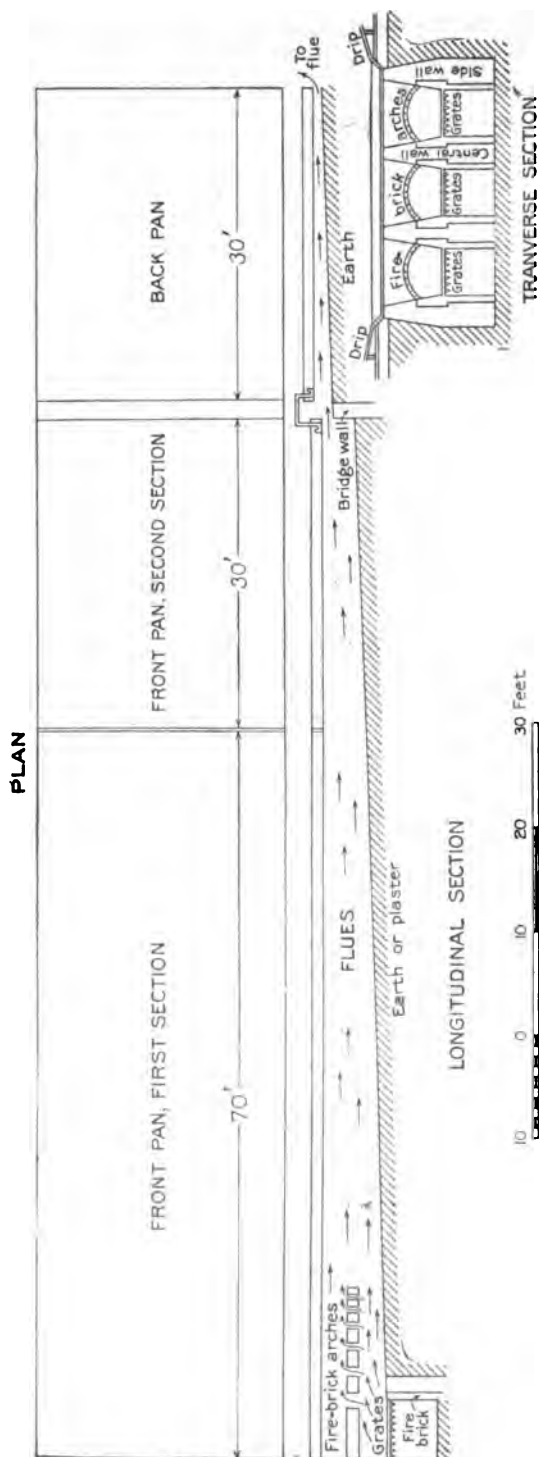


FIGURE 1.—Plan and sections of pan block.

pan in which the salt is made. In Michigan the pans are usually not as long or as wide as in New York and Kansas. The brine is first run into the back pan and after being heated by the hot gases from the fires it is siphoned into the front pan. In New York and Kansas the front pan may have two sections, the salt being made in the one nearer the fire, which is usually the longer.

The fuel used in the eastern States is coal, but in Kansas natural gas is employed except in winter when either coal or crude oil may have to be substituted for it. Pans heated by oil or gas differ in details from those heated by coal.

When sufficient salt has separated in the front pan, this salt is removed to the drain board, built along the flaring sides, and allowed to drain there. In the meantime, the front pan is refilled with brine from the back pan which, in turn, is refilled from the settling tanks. Hand rakes are generally used to remove the salt, but in Kansas

some mechanical rakes are used. Mechanical raking is more common, however, in the grainer process.

Modifications of the method of manufacture outlined above and many details connected therewith are described under the different State headings.

CHARACTER OF PRODUCT.

The open-pan process of making salt is employed in New York, Michigan, Kansas, and Utah, and the modes of operation at some works differ materially. The process, though not extensively employed, has its advantages, one of these being the ability to control the grain of the product. To obtain a fine-grained salt, rapidity of crystallization is essential, and this is procured by allowing the brine to boil. Sometimes artificial means are employed, such as the addition of lard, tallow, or butter to the surface of the brine to break up the grain. When salt is made thus rapidly the pans have to be drawn oftener than when coarser-grained salt is being made by the slower process.

PRACTICE IN WYOMING COUNTY, N. Y.

The general operation of the open-pan process is well illustrated by practice in New York. The brine is pumped from the wells into the settling tanks, often during the night to economize time and the use of machinery. After the brine has remained in the settling tanks for 24 hours to allow the escape of hydrogen sulphide and other gases, a thin emulsion of lime is added, and the brine aerated with a current of air to insure thorough mixing. The lime precipitates any iron in the brines. Twenty-four hours after the addition of the lime soda ash may be added, particularly if the salt is to be for table or dairy use. The brine is allowed to stand sometimes seven days in all, but the length of time depends largely on the condition of the trade.

The shallow pans are made of riveted wrought-iron plates three-sixteenths to one-quarter inch thick. The two compartments of a pan are separated by a partition of wood or metal, and are commonly known as the front pan and the back pan. The pans are usually about 115 feet long, including the two compartments, 27 to 30 feet wide, and 18 inches deep. At the plants in New York, where measurements were given to the writer, the back pan was 43 to 48 feet and the front pan 66 to 72 feet long.

The brine, after having been heated in the back pan, is siphoned into the front pan, where crystallization takes place. The ends of the pans are at right angles with the bottom. The sides flare, and upon the drain boards, built out beyond the flaring sides and extend-

ing along them the salt is raked and left to drain after crystallizing in the pan.

The large front pans rest on two side and two inner brick walls, lined with fire brick where exposed to high temperature and with ordinary brick farther back. Fire-brick arches are built within the walls where the heat is most intense. The arch directly over the fire is longest and extends a few feet back of the grates. An open space follows this arch, then a shorter arch, and so on backward for a distance of 20 feet, the arches becoming shorter and the open spaces longer. The flue space under the back pan is reduced to the practicable minimum. "Draft" is supplied by means of blowers.

The brine runs first into the back pan, where it is preheated by the hot gases from the fires, thence it passes through siphons into the front pan, passing from the back to the front section of the front pan in plants where the front pan itself is divided. When the front pan is full enough the flow is stopped. When sufficient salt has separated in the front pan it is removed to the drain board. Generally, the salt is allowed to drain at least three hours, the front pan being in the meantime filled with warm brine from the back pan and the latter in turn refilled from the settling tanks. The control of the grain can not be maintained satisfactorily while the brine is in commotion, which is the reason for the procedure outlined above. Care must also be exercised not to allow cold brine to go to the front pans for the same reason. At regular intervals the bittern is allowed to go to waste, the pans are scaled—that is, the crust of gypsum adhering to them is removed—and the operation is started anew. Sometimes the pans are coated with whitewash before brine is turned into them.

PRACTICE IN MICHIGAN.

The open pan is also used in Michigan, but the general method of operation is not greatly different from that in New York. The pans are made of $\frac{1}{4}$ -inch boiler plate, riveted to form a pan 80 or 90 feet long, 18 to 20 feet wide, and about a foot deep. The draining boards, on the flaring sides, are about 3 feet wide and run the entire length of both sides. The pan is, as usual, supported at the sides and one end by brick walls, the furnaces being under the other end. Two methods of heating are in use. In one, heat passes directly from the furnace at the front end of the pan to the chimney in the rear. In the other, partitions divide the space below the pan into three compartments or flues, two of which pass from the furnace to the back of the pans and open into the third, through which the smoke and gases pass to the chimney near the furnace.^a

^a Cook, C. W., *The salt industry of Michigan*: Mich. Geol. and Biol. Survey Pub. 8, Geol. series 6, 1913, pp. 320-321.

At a plant in Saginaw Valley where the open-pan process is used to make salt in connection with the manufacture of bromine and calcium chloride, the bromine is first removed and then the salt; a reversal of the order followed at Pomeroy, Ohio, Mason and Malden, W. Va., and formerly at Pittsburgh, Pa.

The natural brine contains dissolved iron which precipitates as the basic oxide on exposure to the atmosphere. After the bromine has been removed sodium, calcium, and magnesium chlorides are the principal compounds that remain, and the brine is said to be slightly alkaline in reaction owing to the presence of hydroxides. The liquor is pumped into large settlers, in which it is treated with milk of lime in excess and mechanically agitated for 2 hours and then warmed with exhaust steam 12 to 24 hours. The clear brine then flows into a cast-iron pan containing a saturated brine, where it is heated in a lower tank or pan, which is much smaller than the corresponding pan used in New York. The brine is boiled, more being constantly added from the preheating pan until the end of a run. After the continual addition of brine containing calcium and magnesium salts and sodium chloride and the continual removal of the latter salt has increased the density of the solution to a certain point, no more brine is added and all the salt practicable is allowed to separate. The residual bittern is then evaporated for the recovery of calcium chloride. Mechanical rakers carry the salt from the bottom of the lower pan to the floor of the upper pan, where the salt is washed with fresh saturated brine from the settlers. The salt then ascends a long slide, draining in the meanwhile, and is conveyed to the bins.

The method of washing frees the salt from magnesium and calcium compounds especially. As gypsum is rare in the brine from the Marshall sandstone in the part of Saginaw Valley where this process is used, considerable trouble and expense are obviated. It is understood that the pipes are not scraped, but simply washed every three or four weeks.

PRACTICE NEAR HUTCHINSON, KANS.

The open-pan process used by a few firms around Hutchinson, Kans. (Pl. XI, A), does not differ fundamentally from that used in New York. The pans are arranged side by side, several of them in the same plant. They are 100 to 118 feet long, 23 to 24 feet wide, and the brine in them is approximately 1 foot deep. The brine is pumped from the well to the settling or storage tanks and thence directly to the pans, which are usually whitewashed. The pans are separated into at least two and at some plants three compartments. Where three compartments are used each of the two back compartments are 14 feet long, and the front one is 90 feet long. Where two are used the back one is only 8 feet long, whereas the front or salt-making compartment is 92 feet long; but where this arrangement is used the brine

is heated by the chimney gases at the base of the chimney. The brine is preheated by the hot flue gases in the back compartment prior to passing to the front.

At one of the plants the brine from the storage tanks passes first into a small double-walled cylindrical tank in the base of the chimney, in which the brine is heated in an annular cylinder 18 inches wide and 20 feet deep, shaped as shown in figure 2. The chimney gases pass out through the central hollow part of the cylinder. It is evident that the preheating part of the pan proper need not be so long where this device is used.

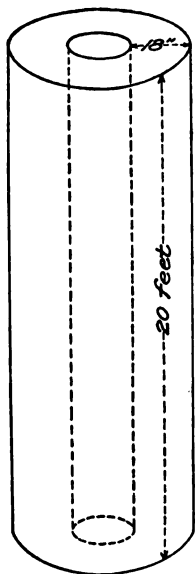


FIGURE 2.—Preheating tank for brine at base of chimney.

Natural gas is used for fuel except during winter, when coal or crude oil has to be used if the pans are operated. The gas burners are arranged along the sides of the front compartment of the pan, a pan 115 feet long being provided with nine lateral burners on each side of the front section and one main burner in the front. The number of lateral burners used depends on the desired grain of salt. Some of the pans are flared along their sides and provided with drip boards, and in some mechanical rakers move the salt forward to the end of the pan and over an end drip board, though the latter method is more in vogue in the grainer process. The salt is raked onto the lateral drip boards, where these are employed, about every two hours and allowed to drain one hour before being taken to the storage bins.

The salt is allowed to remain in bins at least 30 days before being barreled or shipped. The pans have to be scaled every 25 or 30 days, the bittern in them going to waste.

PRACTICE IN SEVIER VALLEY, UTAH.

A small quantity of open-pan salt is made near Redmond, in Sevier Valley, and formerly was made also in Salt Creek Canyon east of Nephi, Utah. (Pl. XI, B.) In the Sevier Valley rock salt from neighboring open-cut mines is the source of the raw material, whereas east of Nephi a brine flowing from a salt spring is utilized. The rock salt in the form of coarse lumps obtained by ordinary mining is dissolved in a small wooden tank outside the plant; the brine thus formed is run into small oblong iron pans, about a foot deep, over wood or coal fires. The brine is boiled vigorously, and as evaporation progresses fresh brine is run in. The salt is raked from the bottoms of the pans at intervals; after it has been dried and ground it is bagged, and at least part of the product is sold for table use.



A. OPEN-PAN ROOM, WESTERN SALT WORKS, HUTCHINSON, KANS.



B. TYPICAL COUNTRY SALT PLANT, 8 MILES EAST OF NEPHI, JUAB COUNTY, UTAH. THE BRINE IS EVAPORATED IN SMALL OPEN PANS.

STEAM EVAPORATION.

EVAPORATION IN JACKETED KETTLES.

In past years some salt blocks in the Wyoming Valley, New York, had kettles that were supported in a framework and surrounded by a steam jacket covered with nonconducting material instead of being suspended in a framework of brick or masonry and exposed to the direct heat of the fires as in the open-kettle process. The jacketed kettles could be uniformly heated, and their walls were thin enough for economical transmission of heat. Thus the grain of the product turned out was uniform and the salt itself of good quality. So far as known, no jacketed kettles are now used in New York State.

GRAINER PROCESS.

GENERAL PRINCIPLES OF SALINE DEPOSITION.

If a saturated solution of a salt is concentrated by evaporation, part of the salt is deposited in crystalline form until the solution has again reached equilibrium of saturation. Different salts possess different degrees of solubility, or, in other words, different proportions of them saturate a given volume of water at a given temperature. Therefore, if a solution containing equal amounts of several salts is gradually concentrated by evaporation one salt first reaches its point of saturation and begins to crystalize and form a deposit before the others; subsequently another salt reaches its point of saturation and forms a deposit mixed with more or less of the first salt, which is still being deposited. Finally, after all the water except that retained in the crystals has evaporated there remains a series of deposits, the deposit of the salt that first reached saturation being at the bottom, the most soluble being at the top. If the supernatant liquid is removed before the second salt reaches its point of saturation, the deposit of the first salt is only slightly contaminated by adhering solution and can be rendered very pure by being dissolved in fresh water and recrystallized. This is the principle of the ordinary process of purification by fractional crystallization.

If, on the other hand, more of the original mixed solution is added before the second salt begins to crystallize the concentration of the first salt is decreased less than that of the others, and the deposition of it is thereby retarded less; consequently a thick deposit of the first salt may gradually be formed by continuous evaporation and successive additions of mixed solution, until finally the concentration of the other salts in the solution becomes so great that they also are deposited. This is the principle of separation followed in the grainer process. These fundamental processes, which can be demonstrated in any laboratory, are generally believed to have been those that formed natural saline deposits.

GENERAL CONDITIONS AS TO USE OF WASTE HEAT.

The following information with respect to the general conditions surrounding the use of waste heat is given by Willcox,^a who has had a wide experience.

The low price of salt that has prevailed for several years past and which, according to present indications, will continue for some time to come, has brought forcibly to the attention of salt producers the necessity for economy in the operation of their plants. The low price of salt, the continually increasing cost of labor, and the troubles experienced on account of strikes, etc., have had the effect, first, of introducing labor-saving machinery into salt plants, and second, of awakening the interest of salt producers in the problem of introducing more efficient means for settling and evaporating brine.

Certain arrangements of evaporating apparatus and methods of operating it have grown up as the result of experience in each salt-producing district of the country. Each district, therefore, follows the methods that have been found suited to its individual requirements, and these methods have in the course of time become standard practice for that district. In some sections much study has been given to the problem of brine evaporation, and a voluminous literature has been contributed to the chemistry of salt production. Not so, however, with the engineering side of the problem.

In certain sections, owing to the abundance of cheap fuel and for other reasons, little study has been given to the subject of economical evaporation. In such districts the quantity of output has naturally been the main consideration.

The standard practice in each salt-producing section has been subject to little change or improvement until within the last 10 years, and these changes and improvements have in large measure been necessitated by the low price at which salt has had to be sold.

The manufacture of salt, more especially by the grainer process, is often carried on in conjunction with some other industry. In Michigan, the industry grew up largely as an adjunct of lumbering and is still carried on in connection with it. In other places salt making is related to some local industry. Thus, at Cleveland, Ohio, near Ithaca, N. Y., and at Pomeroy, Ohio, exhaust steam is supplied from the neighboring plants of traction companies, and in one instance the heat for salt making comes from an electric plant of a closely associated mining operation. Advantage had to be taken of the low cost of heat.

In many places heat is employed that otherwise might go to waste, such for example, as that contained in the condenser or tail-water gathered from all parts of a plant, and in a few places economizers are used that utilize the heat of the chimney gases. Such methods are described more in detail under the heading of "Preheating" in the following pages, and under the local discussion by States. To sum up, it may be stated that many salt plants exist simply because of some decisive advantage, one of which is cheap and readily available fuel.

^a Willcox, G. B., *Evaporation tests of a salt grainer: Michigan Engineer*, 1907, pp. 164-165.

MANIPULATION OF BRINE.

PUMPING.

The brine usually comes from several hundred feet below the surface—in places as much as 2,300 feet. Several methods are used for raising or lifting the brine to the surface; among the more common are there: (1) The air lift or Pohlé system, (2) the hydraulic method, and (3) the old-fashioned sucker-rod and walking-beam pumping system.

In the air-lift system air under pressure is forced down a pipe within the tubing of the well, in which the brine is standing. Rising bubbles of air lift the brine, which is thoroughly aerated—the air escapes as the brine leaves the pipe to enter the first settling tanks. This system of lifting brine is in common use in New York and in certain salt-making districts in Michigan, Ohio, and Texas. Details in applying the method vary in different fields and perhaps in the different plants within the same field.

In certain parts of the Michigan field, brine is also raised by hydraulic pressure; that is, by forcing water into the wells under great pressure, as a result of which the brine is forced out at the same time either from the same or a different well. The water is forced down the outer pipe or casing and the brine flows out of the inner pipe or tubing. In some places underground solution of the salt has progressed so far that the "cavities" of separate wells have merged, and at one plant as many as four "cavities" are known to be connected underground. It is stated by some operators that the method of lifting brine by hydraulic pressure is more satisfactory than by the air-lift method, because a stronger brine is obtained more cheaply and with less destruction of machinery. At some Ohio plants the brine is lifted by the air lift and the air is liberated at the well to avoid jarring the pipes and air compressors. In one plant in Ohio a combination method is employed, the brine being forced to within 800 feet of the surface by hydraulic pressure and the remainder of the distance by means of the air lift. Hydraulic pressure is in use in New York, Michigan, and Kansas. In Kansas the fresh water used in the vicinity of Hutchinson and Sterling is part of the underflow of the Arkansas River and comes from a depth of 30 to 35 feet.

In eastern Ohio, West Virginia, and Pennsylvania, and in certain parts of the Saginaw Valley, the sucker-rod and walking-beam system of pumping has been employed, but modern deep-well pumps are also used at certain plants in these States. The present tendency is toward the complete displacement of the old-fashioned rod and walking beam in favor of the air lift. Along Ohio River the old-fashioned methods have passed into history.

CLARIFYING.

After being pumped to the settling tanks, the brine is allowed to stand long enough to permit the escape of gases—chiefly hydrogen sulphide—considerable quantities of which are present in the brine of certain wells in New York and Michigan; and also to allow the oxidation and precipitation of as much iron as possible. The aeration may also be accomplished, for example, in certain parts of the Saginaw Valley, simply by agitating the brine and allowing it to stand. In plants in the Saginaw Valley, where such preliminary mechanical aeration is carried out, the brine passes directly to the settling tanks, where milk of lime is added, either mechanically or by hand, and the brine is agitated and allowed to stand, sometimes for several days if the storage capacity is exceptionally large.

After standing in contact with the air or after mechanical aeration, brine is treated with milk of lime and thoroughly plunged and mixed, after which it is allowed to stand long enough to settle completely—the length of time depending upon the demand for salt. To remove the excess of lime, soda ash is added at some plants, and the solution is allowed to stand still longer.

In northeastern Ohio milk of lime is added in the storage tanks, but this treatment has not been found necessary in all localities. At one plant milk of lime is forced underground through the casing and thus into the brine. It is claimed that the resulting brine is clearer than usual and that the impurities settle more rapidly, though the reasons for these results are not very clear to the writer. In Kansas the brine as a rule is not treated either with lime or soda ash.

The settling tanks and the preheating tanks vary greatly both in dimension and in construction, and it has been thought wise to give details under the practice in the different States.

PREHEATING.

To insure good results the brine is allowed to run into the grainers at the rate at which evaporation takes place and at a temperature slightly below that of the brine in the grainer. The brine is raised to the desired temperature outside of the grainer in preheating tanks. These may be as long and as wide as the grainer, but they are usually deeper and hence of greater capacity. The heat employed is that which might otherwise go to waste, such as that in the condenser or tail water gathered from all parts of the plant, exhaust steam, etc. Whenever there is a surplus of steam, as during the lifting process, direct steam may be employed. Sometimes two sets of preheaters are in use, tail water being employed in the first, and, in the second, to raise the temperature still higher, exhaust steam is used. In rather rare instances what are known as economizers are in use, whereby the heat of the chimney gases is utilized. The economizers

consist of many flues in contact with the brine. As the chimney gases pass through the flues to the chimneys they give up their heat to the brine. In such cases the draft is assisted by a fan.

Because of the peculiarities of practice in southern Ohio and West Virginia, owing to the dilute brine used in those States and also to the industrial conditions differing from those in other salt fields, the general subject of preparing the brines for making the salt by the grainer process is described in detail under the different geographic headings.

OUTLINE OF PROCESS.^a

The grainer or Michigan process of making salt is of American origin. Briefly, it consists in passing live or exhaust steam through metal pipes that are immersed in the brine to be evaporated. The brine is contained in the grainer, a long, narrow, shallow vat built of wood or metal supported on a framework, or of cement or concrete supported on a foundation of sand.

In some districts the process is carried on efficiently, care being taken to conserve the heat wherever possible and to handle the salt as little as practicable. Such plants have usually been able to survive the keen competition everywhere evident in the salt industry. On the other hand, many grainer plants have advanced little during recent years and have steadily decreased their output; some have shut down altogether. Many of the plants exist simply because of some overwhelming advantage, such as cheap and readily available fuel or a market for bromine, calcium chloride, or other by-products.

The output of a grainer varies considerably, depending (1) on whether live or exhaust steam or "tail water" (hot water gathered from different parts of the plant) is used for heat; (2) on its size; and (3) on the general efficiency with which operations are conducted. In those plants where the so-called dividend grainers are used and where the process of making salt is slow the yield is naturally smaller than in plants where exhaust steam is used. The length of time a grainer runs before being cleaned is a variable factor, but great length of time between clean-ups does not signify that the resulting salt is of poor quality, for at some of the grainers it is the aim to have the process a slow one and to make the grain of the product correspondingly coarse.

As the details of the grainer process as carried on in various districts of this country differ markedly they are described by States in so far as such treatment is advantageous, in addition to the general

^aChatard, T. M., Salt making processes in the United States: U. S. Geol. Survey Seventh Ann. Rept., 1888, pp. 518-526; Merrill, F. J. H., Salt and gypsum industries of New York: New York State Mus. Bull., vol. 3, No. 11, 1893, pp. 58-60; Willcox, G. B., Evaporation tests of a salt grainer: Michigan Engineer, 1907, pp. 164-189; Willcox, G. B., Salt manufacture: Trans. Am. Soc. Mech. Engr., vol. 30, 1909, pp. 1065-1065.

descriptions in this place. Many of the statements made, both here and under the State headings, are general, and practice may diverge considerably in individual plants, though all the general statements are based on actual practice.

CONSTRUCTION OF GRAINER.

The grainer may be built of wood, metal, or reinforced concrete. It must remain brine-tight under great differences of temperature. The old wooden grainers, especially in Michigan, were made of white pine, which was then plentiful. The pine grainers withstood the action of the brine splendidly, were easily made, did not shrink much, and when properly caulked with oakum gave good service for about five years. Some of the wooden grainers used are built of hardwood; grainers with sides of beech and bottoms of maple were called to the writer's attention in Michigan in 1911. The reinforced-concrete grainer, a more recent type, is monolithic, has no expansion joints, and is usually provided with mechanical raking devices. It rests on a bed of rammed sand, which gives uniform support and reduces loss of heat by radiation. Its walls are 5 to 7 inches thick and the bottom 4 to 6 inches thick, the reinforcement being $\frac{1}{4}$ -inch steel bars.

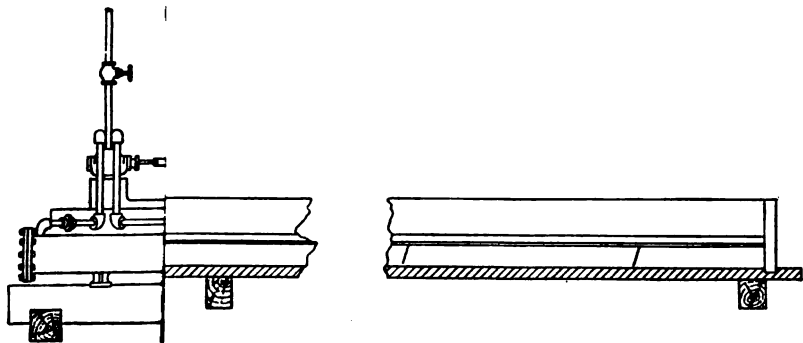
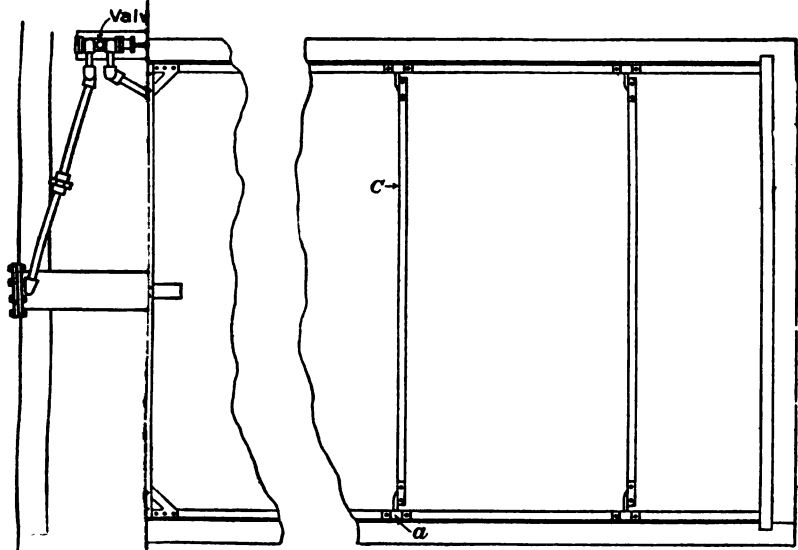
The following data regarding a type of mechanically raked grainer (Pl. XII) that is rather widely used in New York, Michigan, Ohio, and Kansas are taken from Willcox.^a Many modifications of the mechanically raked grainer are giving satisfaction

MECHANICAL RAKERS.

During the process of evaporation it is necessary to "lift" the salt that collects on the bottom of the grainer. The salt is lifted either by hand when the grainer is nearly full or automatically as fast as it forms. The automatic method has been generally adopted, because it is less expensive in the long run and obviates the difficulty of procuring laborers to work in the hot steam-laden atmosphere of the grainer room. Various types of salt raker have been developed, their object being to collect the salt and deliver it to the incline or "apron" at the end of the grainer. In whatever manner constructed, mechanical rakers must be capable of keeping clean a floor 100 to 150 feet long and 12 feet wide, and they must deliver the salt to the incline at such rate as will allow it to drain properly before being pushed into the mechanical conveyors for delivery to the warehouse.

Iron or steel rakers are usually used, but these metals are strongly attacked and rapidly deteriorate in a salt-laden atmosphere. Moreover, the iron salts formed by their destruction discolor and thereby cheapen the product. Chains formerly used in the construction of

^aWillcox, G. B., *Salt manufacture*: Trans. Am. Soc. Mech. Engr., vol. 30, 1909, pp. 1065-1085.



ENGINEERING CO., SAGINAW, MICH.)

salt rakers have been discarded at some plants on account of their liability to break. Wheels also are usually avoided on account of the rapidity with which they wear out in the salty atmosphere. Overhead framework is not desirable because it obstructs the brine surface. For these reasons the most satisfactory automatic rakers are entirely submerged in the brine and are operated by a hydraulic cylinder, placed in front of the grainer beneath the grainer pipes. By this expedient corrosion is reduced to a minimum and no difficulty is experienced from red salt.

The raker (Pl. XII) consists essentially of a framework comprising two steel angles *A* within the grainer near its bottom and adjacent to the side walls. At intervals these two angles are connected by cross braces *B*, and the framework so formed carries a series of feathering scraper blades *C* extending across the grainer and supported at either end on the two side angles by horizontally projecting rocking pivots or fingers, *a*. The scrapers are usually placed about 8 feet apart, and the entire raker has a back-and-forth movement of about 9 feet, so that each blade travels about 1 foot ahead of the initial position of the next blade in front. The salt is thus gradually passed to the front of the grainer and up the incline.

The side angles slide back and forth on a series of flat cast-iron shoes at suitable intervals along the bottom of the grainer. The piston rod of the hydraulic cylinder passes into the grainer through a stuffing box in which are several rings of metallic packing. The cylinder is usually about 8 inches in diameter with a 9-foot stroke. It makes a stroke in about two minutes, bringing up a load of salt every four or five minutes.

BELT CONVEYORS.

On a dry day the salt may be seemingly dry and behave like granulated sugar in the conveyors, but it becomes soggy with increased humidity, and brine will drip from the conveyor on a damp or foggy day. If the conveyor is a belt, the salt on a dry day can be readily cleaned from it by means of a diagonal scraper of plate glass, but on a wet day will stick to the belt, so that removal by any cleaning device is exceedingly difficult. Another difficulty with belt conveyors having iron rollers is excessive corrosion, the underside of the belt becoming covered with iron rust that sooner or later under the sweating of the salt causes rusty water and pieces of discolored salt to drop on the salt piles. A suggested substitute for the iron rollers is an idler made of pepperidge, a kind of wood, about 5 inches in diameter and 2 or 3 inches longer than the width of the belt and having a cold-rolled shaft. The bearings are blocks of well-seasoned maple and ordinary cup grease is used as lubricant. If a conveyor belt is operated continuously for a long time, dirty salt accumulates along the edges and around the rollers at the edges.

ALBERGER PROCESS.

The salient points of the Alberger process, a modification of the grainer process patented by Williams, Alberger & Alberger^a are outlined below.

One of the fundamental essentials of the grainer process is preliminary purification of the brine. Purification from such substances as the sulphate and carbonate of lime is effected by heating the brine in a "purifier" to about 250° to 300° F., thus rendering the impurities insoluble. The purifiers are generally cylindrical, but some are said to be larger at the bottom than at the top, and they are generally made of boiler plate. According to a recent patent, purifiers are partly filled with ordinary gravel about three-quarters of an inch in diameter. The brine under pressure enters the purifier where the impurities are deposited in the gravel and on the internal surface of the purifier. By rotating or agitating the purifier so as to cause the deposition surfaces to rub one another and the interior of the purifier, the impurities are broken away; then they are removed by flushing or any other convenient method.

The grainer used in the Alberger process is a circular evaporating pan, which is filled with brine to a depth of about 1 foot. Attached to its bottom and opening into it at a point on its periphery is a mixer, into which the salt is swept from the bottom of the grainer by arms and scrapers on a revolving shaft. Arms on another shaft sweep the surface of the brine in the grainer and agitate it with "flippers." The arms and scrapers revolve slowly to avoid stirring the contents of the grainer too much and are submerged; the flippers at the surface revolve more rapidly. Brine is fed continuously. The steam pipes in the grainer are supported outside, so as not to interfere with the operation of the rakes.

After having been suitably prepared in the purifier and heated to the proper temperature (226° F.), the hot brine spreads over the surface of the grainer. The flippers strike the salt as it forms in small crystals on the surface of the brine and cause it to fall to the bottom. They also strike a dam or obstruction, so that the salt adhering to them is knocked off. The arms and scrapers revolving slowly aid the circulation of the brine and sweep the salt as it forms from the center to the periphery of the grainer, from which it passes to the mixer and then to the centrifuge, where it is partly dried. If it contains no insoluble matter, it passes to the steam drier and then to the bolters and sifters, where it is finished for the market.

^a Williams, H., Alberger, J. L., and Alberger, L. R., U. S. Patent 400,983, Apr. 9, 1889; also U. S. Patent 351,082, Oct. 19, 1886; and U. S. Patent 443,186, Dec. 23, 1890.

PRACTICE IN NEW YORK.

The brine, from the well goes to settling tanks (Pl. XIII, *A*). Then, at some plants, it is allowed to stand 24 hours to allow the escape of hydrogen sulphide and other gases. It is then treated with a few buckets of milk of lime and thoroughly plunged, after which it is allowed to stand 1 to 3 days or even longer, the length of time depending on the demand for salt. To remove the excess of lime, soda ash is added at some plants and the solution again allowed to stand 24 hours or longer. To obtain good results the brine is then allowed to run into the grainers at the rate at which evaporation takes place and at a temperature only slightly below that of the brine in the grainer. The brine is raised to this temperature outside the grainers in preheating tanks (Pl. XIII, *B*), which may be as long and as wide as the grainers but are usually deeper and hence of greater capacity. These contain steam pipes placed a foot or so above the floor to heat the cold brine. The exhaust steam from the grainer pipes is the usual source of heat but "tail water"—hot water gathered from other sources throughout the plant—may also be used. Whenever there is a surplus of steam, as during lifting, direct steam may be employed. The preheating tanks are usually in the grainer building and the settling tanks outside.

In New York, grainers 100, 120, 125, 128, and 140 feet long are in use; they are usually 12 feet wide and 20 to 24 inches deep. They are provided with 4 to 8 steam pipes, 2½ to 5 inches in diameter, hung on pendants so that their tops are a foot or less from the bottom of the vat. These pipes are almost as long as the vat and are so arranged that the salt can be raked to the outer side of the grainer.

In grainers in which hand-lifting is employed the salt is shoveled from the grainer to a platform (Pl. XIV) built over and running lengthwise of the middle. Usually salt is removed from such grainers once a day and, after having drained enough is carried in wheelbarrows to the storage bins. In many plants the salt as it forms is continuously moved by mechanical rakers to an inclined plane or "apron" at one end of the grainer, from which the bulk of the adhering bittern flows into the grainer again. Where the salt is removed by mechanical rakes it may fall on a revolving belt, and be conveyed by a bucket elevator to the storage bins without manual labor; or it may be shoved over the end of the apron onto a shelf whence it is removed in wheelbarrows. For best results the brine should be kept at or near the boiling point while the salt is being removed.

To keep the salt at the highest standard particularly if it is intended for table or dairy use, the bittern containing the chlorides of lime and magnesium must be removed every day, every other day, or every third day, depending on the quality of salt that is being made.

As the bittern contains too much salt to be allowed to go to waste it is discharged into another set of grainers known as "dividend" grainers, which are heated by waste or exhaust steam and "tail-water." Because of the low temperature and the consequent slowness of crystallization in these grainers the salt is rather coarse-grained and is used chiefly for meat packing and refrigerating.

Many of the main grainers, from which salt is lifted daily, have to be cleaned and scaled every 3 or 4 weeks, though some are scaled only two or three times a year. The frequency of cleaning depends on the calcium sulphate (gypsum) content of the brine, and large amounts of calcium sulphate are common in the brines of New York.

PRACTICE IN MICHIGAN.

DEVELOPMENT.

For descriptive purposes Michigan may be divided into three districts as follows: (1) Western part of the Lower Peninsula, including Manistee, East Lake, and Ludington; (2) the Saginaw Valley, including the region about the cities of Saginaw, Bay City, Midland, St. Charles, and Mount Pleasant; and (3) Detroit and to the north and south along St. Clair and Detroit Rivers. The grainer process in this State does not differ in principle from that in New York though it varies in details. Both the grainers from which the salt is lifted by hand and the modern mechanically raked grainers are in use.

Salt making in Michigan was at first only an adjunct of lumbering—refuse lumber and exhaust steam being used for heat. Now the manufacture of salt has become so important as to be an integral part of the business, though it is still a side issue with many firms, and some firms will undoubtedly discontinue making salt as lumbering declines. In general, however, the manufacture of salt in this part of Michigan is so well established that even the decline in the lumber business is not likely to seriously affect it; probably it, like other industries, will adjust itself to changed conditions and will continue to thrive. There will be a change in fuel from wood to coal, and greater economy in utilizing heat.

LUDINGTON-MANISTEE DISTRICT.

In the Ludington-Manistee district, which includes Manistee, East Lake, Filer City, and Ludington, more mechanically raked grainers are in operation than those from which the salt is lifted by hand, and at some plants the latter type of grainer serves simply as a complement of the other, utilizing available waste heat and making a coarse salt for which there is good demand.

The brine near Manistee is pumped from a depth of approximately 2,000 feet, usually by means of air lifts. The wells at Ludington are reported to be about 2,300 feet deep. The ordinary strength of brine



A. OUTSIDE SETTLING TANKS, WORCESTER SALT PLANT, SILVER SPRINGS, N. Y.



B. PREHEATING TANKS, WORCESTER SALT PLANT, SILVER SPRINGS, N. Y.



A. GRAINERS IN WHICH SALT IS LIFTED BY HAND, WORCESTER SALT PLANT, SILVER SPRINGS, N. Y.



B. GRAINERS AT LIVERPOOL SALT PLANT, HARTFORD, W. VA.

pumped varies from 90° to 100° salimeter. At some of the plants it runs from 98° to 100° continuously if the wells are not crowded; otherwise the strength may decrease to 97° or 95°. At most wells the water that dissolves the salt underground is not pumped into the beds, as in some other fields, but flows in from overlying strata as brine is pumped out; at some wells, however, the water is forced in.

The brine flows from the wells through troughs, or stands in tanks in order to insure elimination of hydrogen sulphide. It then passes through the settling and preheating tanks to the grainers.

The settling tanks in the first set differ greatly in their dimensions. At some plants they are less than 100 feet long, but most of them are 100 to 160 feet long. They are usually 12 to 24 feet wide, a width of 18 feet being common, and are 6 to 8 feet deep. The preheating tanks are 150 to 195 feet long, though one seen by the writer was 300 feet; they are 10 to 15 feet wide, one wider having been noted; and are usually 6 to 8 feet deep. Some are constructed of concrete. These tanks are provided with several 3-inch or 4-inch pipes, through which live steam, tail water, or exhaust steam is passed. So far as the writer is aware, no chemicals are used to prepare the brine for the grainers, though practice may have changed since he visited the field. The brine is heated usually to a temperature of 120° to 160° F., but at some plants, especially those where the brine is weaker than usual, the temperature may rise to 175° F. In places four days are consumed in the passage of the brine from the wells to the grainers.

The grainers are heated more generally by exhaust than by live steam. Where a hand-lifted dividend grainer is a minor part of the establishment, tail water or exhaust steam is generally used to heat it. The grainers are usually 150 to 160 feet long, 10 to 13.5 feet wide, and 18 to 24 inches deep. They are fitted with 6 to 8 and sometimes 9 or even 10 galvanized-iron steam pipes, usually 4 inches in diameter. Some of the grainers in which hand lifting is practiced are shorter than those mentioned, but their width and depth usually fall within the limits given.

The grainers make 60 to 75 barrels of salt in 24 hours, 80 barrels being a maximum. The production depends on so many variable factors that information on this point can not be very definite.

SAGINAW VALLEY DISTRICT.

In the Saginaw Valley district, which includes Saginaw, Bay City, Midland, Mount Pleasant, and St. Charles, brine comes from different depths. In Saginaw the salt wells are 700 to 900 feet deep, at Bay City about 1,000 feet, and at St. Charles 800 feet deep. At Midland the brine-bearing horizon is approximately 1,200 to 1,300 feet below the surface, and at Mount Pleasant the brine supply at one well lies between 1,408 and 1,463 feet below the surface. In places the brine

is somewhat dilute, its salimeter strength varying from 80° to 94°, 100° representing complete saturation with sodium chloride. It is reported that the brine near the center of the basin registers more than 100° salimeter on account of the presence of calcium and magnesium salts, that are more soluble than common salt.

A far greater number of wells were formerly in use in this valley, especially about Saginaw and Bay City. If all wells had been plugged when abandoned, little fresh water would have reached the natural brine, but, according to information received, many of the old wells were not plugged, and consequently the natural brine has been greatly diluted with fresh water from overlying strata. A State law now makes it compulsory to plug all old or abandoned wells.

The brines of the Saginaw Valley, as shown by the analyses given below and those on pages 81 and 82, contain considerable bromine, calcium, and magnesium. The bromine and the calcium chloride, mixed with the magnesium chloride, beside the salt, are obtained at various plants in the district. The brine at the Dow Chemical Co.'s plant, Midland, is reported to contain ammonium, and some of the brines contain ferrous iron, which precipitates as basic ferric salts on exposure to the air and discolors the brine. The specific gravity and the bromine content of the brine increase toward the center of the basin, as the following analyses show:

Analyses of natural brines of Saginaw Valley, Mich.

[Analyst: J. C. Graves, manager Saginaw Chemical Works.]

Constituent.	1	2	3	4
Sodium chloride (NaCl).....grams per liter	11.4	14.7	16.73	0.06
Calcium chloride (CaCl ₂).....do	11.4	8.34	4.11	23.70
Magnesium chloride (MgCl ₂).....do	4.2	3.15	1.76	9.94
Bromine (Br).....do	.172	.13	.0625	.35
Ferrous chloride (FeCl ₂).....do	.06	.045	.005	Trace.
Calcium sulphate (CaSO ₄).....do	.0104	.....	.....	Trace.
Ammonia (NH ₃).....do	.....	.023	.....	.....
Specific gravity.....	27.2424 1.238	26.388 1.220	22.6675 1.182	34.04 1.33

1. Brine, Mount Pleasant, Mich.
2. Brine, Midland, Mich.
3. Brine, St. Charles, Mich.
4. Bittern, St. Charles, Mich.

Though details of construction and operation vary widely in the region around Saginaw and Bay City, only a few details of the manipulation prior to evaporation in the grainer call for specific mention. After the brine has been pumped from the well by the old-time sucker-rod and walking-beam system, or by the more modern methods, effort is made to aerate the brine thoroughly in order to oxidize and precipitate as much iron as possible. This is accomplished by plunging the brine; that is, by agitating it and allowing it to stand a given number of hours, say six or more—the longer

the better. In plants where this preliminary aerating is not done the brine passes directly to the settling tanks, in which it is treated with milk of lime added by hand or automatically, agitated, and allowed to stand—usually from 12 to 48 hours. Where the storage capacity is exceptionally large the brine is allowed to stand in the tanks as long as 6 days.

The tanks used to settle the brine differ greatly in size and construction. They are 18 to 39 feet long, 16 to 26 feet wide, and 5 feet to 6 feet 3 inches deep; their capacity ranges from less than 2,000 to nearly 5,500 cubic feet. At the plant of the Saginaw Plate Glass Co. the tanks are 150 feet long, 20 feet wide, and $7\frac{1}{2}$ feet deep, with a content of 22,500 cubic feet, and are constructed of concrete, the favored material in recently built plants.

From the settling tanks the brine passes to the preheating tanks, which are 100 to nearly 200 feet long, 8 to 12 feet wide, and 5 to 6 feet deep. Each tank, according to its size, is provided with 5 to 10 steam pipes, 3.5 to 4 inches in diameter. Exhaust steam or tail water is commonly used to heat the brine, and the solution may be raised to 180° F. or to the temperature at which salt begins to form before it goes to the grainer. This is not the practice at all the plants. At the Saginaw Plate Glass Co.'s plant the brine goes to a second preheater where exhaust steam raises the temperature above that in the first preheater where tail water only is used.

The grainers are 112 to 180 feet long—150 or 160 feet being perhaps the commonest length, 8 to 12 feet wide, and 16 to 20 inches deep. They contain 5 to 8 steam pipes 3 to $3\frac{1}{2}$ inches in diameter. Tallow, corn oil, or some similar substance is used to "cut" the salt crust on the surface of the brine in the grainer. The hand-lifting process and mechanical rakers are both in use.

There is great divergence in the quantity of salt made daily in grainers at different plants, according to the quantity and kind of salt desired, the volume and kind of steam available, and finally whether salt making is considered a vital part of the establishments. Also on the rapidity of manufacture depends the number of times that the pipes have to be scaled, but this also depends on the proportion of gypsum in the brine, which appears to vary more than might naturally be expected. Some firms, of course, may be more economical of heat than others and remove the gypsum from the grainer pipes oftener.

DETROIT DISTRICT.

The Detroit district includes all the salt-making establishments in the southeastern part of the Lower Peninsula of Michigan; that is, those in the suburbs of Detroit, those southward on Detroit River at Del Ray, Ecorse, and Wyandotte, and those north along St. Clair River at Port Huron, St. Clair, and Marine City.

In this district as a whole, the salt-bearing rocks contain more than one salt bed, and at different places brine is obtained from different beds, though in general the salt-bearing rocks lie at progressively increasing depths northwest from Trenton through Detroit, Marine City, St. Clair, and Port Huron.

The brine is raised by air lifts and by forcing. In the latter system the water is forced down the outer pipe or casing and the brine flows out of the inner pipe or tubing. At one plant underground solution of a salt bed has gone so far that as many as four wells communicate freely. Some operators claim that the hydraulic pressure system is more satisfactory than the air-lift system. The brine as pumped is said to be fully saturated at most plants.

Usually the brine is treated in settling tanks with milk of lime. The brine may be "limed" mechanically as it is pumped into the storage tanks or the milk of lime may be added by the old-fashioned hand method. Then the solution is plunged. After treatment with lime, plunging from time to time, and standing several days, the solution goes to the preheating tanks. The settling tanks usually are 30 to 180 or even 200 feet long, 10 to 20 feet wide, and 7 to 9 or 10 feet deep. In capacity they range from little more than 2,500 to more than 25,000 cubic feet. The preheating tanks are generally heated with exhaust steam, but some are heated with condenser water.

Both mechanical and hand-raked grainers are in common use, especially the Willcox type of mechanical raker or a modification of it. Cement-lined wooden or steel grainers are used as well as the regular wooden type. The grainers are 100 to 150 feet long, 12 feet wide, and 20 to 24 inches deep. They are usually equipped with 3½-inch or 4-inch galvanized-iron steam pipes, but those at one plant have ordinary iron pipes coated with whitewash, which does not contaminate the salt by falling off, because it is baked and thoroughly hardened by passing steam through the pipe before salt making starts. Whitewashed pipes shed gypsum more readily in scaling. The grainers at one plant where they are heated with direct steam are V-shaped, being 18 inches wide across the bottom and 12 feet wide across the top. They are 8 feet deep and about 100 feet long. As the salt forms it is scraped from the bottom by an endless-chain raker or hoe and is dumped into a trough by a pushing device like that ordinarily used in the Willcox raker.

PRACTICE IN NORTHEASTERN OHIO.

The centers of salt manufacture in northeastern Ohio are Cleveland, Cuyahoga County; Wadsworth, Medina County; Akron (Kenmore), Summit County; and Rittman, Wayne County. Brines are utilized in the manufacture of soda products, but not of salt, at Barberton, Summit County, and at Fairport Harbor, Lake County.

In this region the hydraulic-pressure method of lifting brine is used. Some operators claim that the method gives a stronger solution and is easier on machinery than the air lift. At some of the plants, however, the brine is raised by air lifts. At one plant a combination method is used, the brine being forced to within 800 feet of the surface by hydraulic pressure and the rest of the way by air lift. The brine as pumped varies in strength from 94° to 100° salimeter, some of the firms aiming to procure brine slightly below complete saturation to avoid the pipes becoming stopped, as sometimes happens in pumping a fully saturated solution.

At some plants the brine is treated with milk of lime in storage tanks but this practice has not been necessary at all places. At one plant the lime is forced into the wells with the water and the resulting brine is said to be much clearer. In addition, lime is added to the brine in the settling tank, but as a result of the preliminary underground treatment the impurities settle more rapidly. The capacity of the settling tanks is 8,000 to 14,500 cubic feet.

As a rule the majority of the grainers at a given plant are worked more rapidly than the rest; usually the rapidly operated grainers are heated by live steam and the slowly operated ones by the exhaust from them, or the rapidly operated grainers are heated by exhaust steam and the others by tail water. Grainers in which the salt is lifted mechanically and those in which it is lifted by hand are in use, but at any given plant the latter are usually fewer and are heated with exhaust steam or tail water. These arrangements are made in order to utilize all available heat and make a grade of salt that is always in demand.

The grainers are made of iron, of iron lined with cement, or of wood lined with cement. Their lengths range from 80 to 150 feet, their widths from 10 to 14 feet, and their depths from 22 to 24 inches.

FORMER PRACTICE AT PITTSBURGH, PA.

The John A. Beck Salt Co., Pittsburgh, Pa., when in existence, used grainers. The natural brine, obtained at a depth of approximately 1,400 feet and raised by sucker-rod pumping, had a specific gravity of 9° B. After the impurities were precipitated by lime in the storage tanks the brine was concentrated in cylindrical boilers at boiling temperature to a specific gravity of 16° B. The brine then flowed by gravity to four settling tanks, in the first of which lime was used. After standing in the settling tanks about four days and being concentrated to a strength of 20° B. (specific gravity 1.16), the brine went to the grainers.

Each grainer was independent of the others; was 140 feet by 9 feet by 18 inches; and was fitted with three 4-inch copper pipes, through which the steam passed. The salt was lifted by hand to a central platform, 150 barrels being lifted from each grainer every 24 hours.

The bittern was utilized in the manufacture of bromine. The grainers were, with a single exception, quick-acting, and the brine actually boiled in them.

PRACTICE IN KANSAS.

Salt is made by the grainer process at Hutchinson, Reno County; Anthony, Harper County; and at Lyons, Rice County; also formerly at Sterling, Rice County; and Ellsworth, Ellsworth County. In Kansas, Hutchinson is the chief center of salt making by evaporative processes, including in this term the open-pan, grainer, and vacuum-pan methods. Some of the plants in Kansas are designed solely for salt making, but others are designed for manufacturing salt in conjunction with other products, such as ice.

In the vicinity of Hutchinson and Sterling the fresh water for dissolving the salt comes from the underflow of Arkansas River. This underflow contains dissolved mineral matter, so that some of the impurities in the bitterns come from it. The water used in dissolving the salt at Ellsworth came from deep wells.

The brine is raised by hydraulic lift, and pumped into the storage tanks. As a rule the brine is not treated with lime or soda ash. Exhaust steam is generally used for preheating the brine before it goes to the grainers.

Grainers of both hand-lift and mechanical-rake types are in use. They are constructed of steel or cement, range in length from 90 to 180 feet, in width from 11 to 14 feet, and in depth from 18 to 20 inches, and are heated with live or exhaust steam. In some plants the grainer pipes are coated with whitewash and heated prior to making salt, thus making the subsequent scaling easier. Grainers are scaled at intervals of 10 to 30 days. At some plants a little butter or oil is used to break the crust of salt as it forms and thus to hasten crystallization. The plants are equipped to burn gas, but crude oil is used when no gas is available.

PRACTICE IN TEXAS.

Several plants, situated at Palestine, Anderson County, and at Grand Saline, Van Zandt County, produce all the salt resulting from the artificial evaporation of brine in Texas.

The rock salt is dissolved underground, and the resulting brine is raised to the surface by air lifts. The brine is treated with milk of lime in the storage tanks. Most of the grainers have mechanical devices for lifting the salt, but hand labor is used at a few. The grainers are built of steel alone or of concrete or cement lined with tile. Lengths range from 75 to 150 feet, but most grainers are 12 feet wide and 22 inches deep, the depth of the brine in them approximating 18 inches. Rakers with chain attachment are used at one plant. Oil is used at some plants to cut the grain of the salt. At Grand Saline the fuel is lignite, obtained 9 miles away, at Alba.

PRACTICE IN WEST VIRGINIA AND SOUTHERN OHIO.

SALT-MAKING CENTERS.

Salt is made from natural brines at Malden, Kanawha County, at Mason and Hartford, Mason County, W. Va., and across Ohio River from the latter towns around Pomeroy, Meigs County, Ohio. The peculiar treatment of the brines at these localities deserves special description.

The composition of these brines is shown by analyses 13 to 17 in the table on page 82.

PECULIARITIES OF BRINE.

Barium salts are present in the natural brines along the Ohio River. Such salts are not known in appreciable quantities in any other natural brines. These salts are now carefully removed by precipitation with salt cake before the salt-making process begins.^a Also, the Ohio River brines differ from the great majority of, if not all other, natural and artificial brines in being practically free from sulphate of lime. In the evaporation thin copper pipes are used in the different settlers and grainers. Were gypsum present, it would settle on these pipes and they would quickly be ruined by the hammering required to loosen it. The absence of sulphate of lime also is said to account for the salt not hardening.

PRETREATMENT IN MUD SETTLERS.

In the vicinity of Mason, W. Va., the wells are approximately 1,100 feet deep, and the brine is pumped by the air-lift method from a depth of 500 to 600 feet. The strength of the brine is 8° B. (specific gravity 1.058 at 60° F.). The brine goes to storage tanks, and from them to the heating tank. This is 70 by 10 by 2 feet and is divided into three compartments, through which the brine mixed with milk of lime is circulated for the purpose of warming and clarifying it. Instead of milk of lime, alum may be used as a precipitant. The brine is not concentrated in the heating tank, and has actually a lower specific gravity on leaving than on entering the tank because of its higher temperature.

The furnace pans are arranged in four batteries or sections, and the brine is heated by means of refuse coal from mines near the plant. The firing is usually done under one section of the furnace pans. Each of the first three sections contains 10 pans bolted together; each pan is 8 feet long and 3 feet wide, with ends less than a foot high, and sides not quite as high as the ends, except that the two end pans have one side as high as the ends of an inside section, these

^a Skinner, W. W., and Baughman, W. F., The removal of barium from brines used in the manufacture of salt: Jour. Ind. and Eng. Chem., vol. 9, Jan., 1917, pp. 18-28.

sides forming the ends of the section. Each section is thus practically a single pan 30 feet long, 8 feet wide, and slightly less than a foot deep, with low transverse partitions. The fourth section is a single pan of the same dimensions, but without transverse partitions. Above the heating pans is a steam chest, and the low-pressure steam from the boiling brine in the pans furnishes the heat for the subsequent evaporating in the mud and draw settlers and in the grainers. Copper pipes convey the brine from one section to another, and log and iron pipes convey the steam from the steam chest to the settlers and the grainers.

The heated brine flows from the furnace pans to three mud settlers, each 130 by 10 by 2.5 feet and provided with two 5-inch copper pipes. The brine runs into one end of the first settler and circulates round a central partition, leaving the first settler with a strength of 16° B. (specific gravity, 1.124).^a In like manner, the brine circulates through the second and third mud settlers, leaving the latter with a strength of 18° B. (specific gravity, 1.142). Alum is added in the first mud settler to help clarify the brine, and a mud or sludge containing iron oxide separates in these settlers.

From the mud settlers the brine goes to two draw settlers, each measuring 130 by 12 by 4 feet and having four 5-inch copper pipes. In general the brine circulates continually through the draw settlers, but can stand in them until it reaches a concentration of 21° to 22° B. At some plants the brine does not pass through both draw settlers but is concentrated in one of them and passes thence to the grainers.

The brine passes through the grainers in succession as the bittern increases in strength. There are seven grainers in series at the plant described. When the salt is ready to be lifted, that in the last grainer, the one farthest from the draw settlers, is lifted first, after the bittern has been removed to the bromine plant. The bittern in the next preceding grainer is allowed to run into the last grainer and the salt in that grainer is then removed, and so on. Then the first grainer is filled from the draw settlers and the operation is repeated. As a result of this procedure the best salt comes from the first grainer and the poorest from the last. Tallow is used to cut the grain of the salt and to hasten granulation. The salt is lifted once in 24 hours, the period of formation being about 18 hours.

The grainers at this plant are of three different types: (1) Cement with tile floor, (2) wood with cement bottoms and tile floor, and (3) wood with tile floors. The grainers usually contain three or four copper pipes 5 inches in diameter. The salt was formerly lifted by hand onto wooden platforms (see Pl. XIV), but it is now mechanically raked. At other plants the grainers have mechanical rakers

^a To convert Baumé degrees to specific gravity the following formula is correct at 60° F: Specific gravity = $\frac{144.3}{144.3 - B.}$ All the specific gravities mentioned subsequently are assumed as at 60° F.

driven by brass chains on brass cog wheels. Where the latter are used each grainer is independent and is thoroughly cleaned about every six days; the bittern goes to a refuse grainer in which it is concentrated to the strength requisite for the bromine plant. The salt made in the refuse grainers is low grade, but finds a market.

PRETREATMENT BY FILTRATION.

The brine from the wells at Pomeroy, Ohio, which has a strength of about 11° B. (specific gravity, 1.083), is pumped into two circular storage vats; then it flows into a heating tank, where it is heated lukewarm by steam from the evaporator. The heating tank is 40 by 8 by 2 feet and is divided into three compartments.

The brine next goes to an inclosed evaporator, where it is boiled and concentrated to 15° B. (specific gravity, 1.125) chiefly by the exhaust steam from the engines, the steam from the boiling brine being used to concentrate the brine in the settlers and grainers. It then goes to a tank, 20 by 6 by 8 feet, from which it is pumped to two filtering tanks. Each of these is 8 feet deep and 15 feet in diameter, and is filled with sand. One is used while the other is being cleaned; and one is cleaned daily. Fresh water is forced upward through the sand. The wash water is wasted.

From the filtering tanks the brine runs to the two mud settlers, which are 90 by 12 by 3 feet and have three 5-inch copper pipes for steam. The brine leaving the second mud settler has a concentration of 18° B. (specific gravity, 1.142), and is concentrated in a third settler to a strength of 19° B. (specific gravity, 1.151). Thence the brine passes to the two draw settlers, which are 160 by 12 by 5 feet and are provided with copper steam pipes. Each of these is independent of the other, and furnishes its own quota of brine at 24° B. (specific gravity, 1.2) to the grainers. There are six grainers, counting the one that contains the bittern for the bromine plant. Salt is made in the grainers for 6 days and at the end of the sixth day each grainer is emptied, the liquor going to the last or bitter-water grainer, in which it is concentrated to 39° B. (specific gravity, 1.37) for the bromine plant. The salt is removed from the grainers mechanically with rakers on an endless chain.

TREATMENT AT MALDEN, W. VA.

At Malden, W. Va., the brine has an average strength of 8° B. (specific gravity, 1.059) as it comes from the wells. It is pumped to a storage tank measuring 50 by 25 by 4 feet, whence it passes to the preheating tank. There it is heated with steam from the evaporators to 160° F. From the preheating tank the brine passes to three evaporators, two of which measure 30 by 12 feet by 14 inches, and the third 45 by 12 feet by 14 inches. Natural gas and slack coal are

the fuels. The brine from the evaporators has a strength of 11° B. (specific gravity, 1.083) at boiling temperature and goes to the mud settlers. The first and second of these measure 160 by 10 by 2 feet and are divided into two compartments, each containing a 5-inch copper pipe. The third and fourth settlers are 160 by 12 by 2 feet and are divided into three compartments, each containing a 5-inch copper pipe. All are made of wood.

The brine leaves the several settlers at concentrations of 15° B. (specific gravity, 1.116) at 150° F., 17° B. (specific gravity, 1.143) at approximately the same temperature, 19° B. (specific gravity, 1.151), and 21° B. (specific gravity, 1.170); then it goes to the draw settler, a cement-lined wooden frame 160 feet long by 12 feet wide by 2.5 feet deep, provided with three 5-inch copper pipes. In it the brine reaches a concentration of 23° B. (specific gravity, 1.190). From the draw settler the brine goes to the five grainers, through which it circulates in series. The salt is lifted by hand. Two of the grainers are built of wood lined with tile, and three are built of cement. Each measures 160 by 10 feet by 18 inches. As the brine passes from one grainer to another its specific gravity gradually increases from 24.5° to 26.5° B. (specific gravity, 1.204 to 1.225) in the first to 32° to 36° B. (specific gravity, 1.284 to 1.332) in the last. From the last grainer the bittern flows to a reservoir to cool before entering the bromine plant.

RECOVERY OF BROMINE.

Where bromine is obtained from bitterns resulting from the manufacture of salt, it may be said to be an adjunct of the grainer process of salt making. For this reason it has been thought best to describe bromine recovery in this place. It must be remembered, however, that a large part of the bromine produced as such or in the form of bromides in the United States is not connected with salt manufacture.

HISTORY.

Bromine manufacture in the United States dates back to approximately the middle of the nineteenth century. U. S. Patent 12077, issued to Amalie Stieren of Natrona, Pa., Dec. 12, 1854, and reissued, describes an "improved process of treating the mother water of salines to obtain useful products." It describes operations for obtaining magnesium sulphate, iodine, and bromine from the bitter water of saline springs.

This patent was followed by others in the sixties issued to persons living at Freeport, Pa., and to persons living at Hartford City, W. Va., Pomeroy, Ohio, 1873; Clifton, W. Va., 1873; Mason City, W. Va., 1875; Allegheny City, now a part of Pittsburgh, Pa., 1887; and Midland, Mich., 1891. Thus the early inventions serve in part as a geographical index of the localities where natural bromine-bearing brines are known in the United States.

PRODUCTION CENTERS.

Bromine is now made in Michigan at Saginaw and St. Charles, Saginaw County; at Bay City, Bay County; at Midland, Midland County; and at Mount Pleasant, Isabella County. At Midland and Mount Pleasant, the bulk of the bromine is not marketed as the element, but in the form of sodium, potassium, ammonium, and other bromides. In the Ohio Valley, bromine is also made at Pomeroy, Meigs County, Ohio, and opposite Pomeroy at Mason and Hartford, Mason County, W. Va. Malden, Kanawha County, on the Kanawha River, a short distance above Charleston, is also the site of a bromine industry. Until within a few years bromine was recovered at Pittsburgh, Pa., but the weakening of the brine stopped the work.

At most of the localities mentioned above, possibly at all except Midland, Mich., bromine is made in connection with the manufacture of salt and calcium chloride. In Ohio, West Virginia, and in the Saginaw Valley outside of Midland and Mount Pleasant, the salt is first removed from the natural brine, and subsequently the bromine and the calcium chloride, the former by chemical means, sulphuric acid and an oxidizing agent being employed. In Midland and Mount Pleasant different methods of manufacture are employed.

Analyses of bromine-bearing brines are shown in the table following:

Results of analyses of natural brines bearing bromine and calcium chloride.

[Analyses by W. B. Hicks.]

RADICLES IN PERCENTAGE OF ANHYDROUS RESIDUE.

Sample	2	3	6a	6b	7	7a	8	9	11	13	14	15	16	17
K.....	0.86	1.21	1.19	0.79	0.43	0.28	0.36	0.31	0.34	0.35	0.34	0.30	0.32	0.26
Na.....	18.99	22.80	13.04	18.32	29.47	26.50	33.48	31.40	31.89	31.38	31.35	30.78	31.84	28.24
Ca.....	11.51	11.15	17.38	6.65	6.22	6.22	3.33	6.19	11.80	4.82	4.95	5.06	5.00	6.93
Mg.....	4.77	2.42	4.11	3.18	1.78	1.64	1.21	1.41	2.72	1.53	1.35	1.62	1.28	1.70
Cl.....	62.89	61.84	63.66	62.89	61.24	61.80	61.24	61.42	62.69	61.54	61.56	61.83	61.24	62.35
Br.....	.63	.58	.58	.68	.27	.28	.13	.23	.35	.35	.45	.51	.32	.52
SO ₄	.35	.04	.04	.28	.16	.28	.27	.04	.04	.04	.....	.....	.....	.....
100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total solids, by summation.....	17.38	23.95	22.61	28.43	18.49	21.37	22.22	25.62	28.87	8.51	8.90	9.88	9.39	7.65
Total solids, by ignition.....	17.00	24.01	22.04	28.42	18.40	21.10	22.40	25.60	28.98	8.38	8.52	9.99	9.27	7.49
Specific gravity at 23° C.....	1.141	1.194	1.163	1.221	1.143	1.168	1.171	1.202	1.223	1.062	1.066	1.075	1.069	1.067

CONVENTIONAL COMBINATIONS IN PERCENTAGE OF ANHYDROUS RESIDUE.

	KCl	NaCl	CaCl ₂	MgCl ₂	MgBr ₂
1.64	2.31	2.27	1.51	0.82	0.53
47.05	56.91	32.74	48.33	78.51	75.59
31.41	30.90	48.08	39.30	18.25	16.92
18.50	9.21	15.90	12.18	6.88	6.33
.72	.67	.67	.78	.31	.32
100.00	100.00	100.00	100.00	100.00	100.00
0.60	0.61	0.57	0.65	0.67	0.65
78.27	80.29	79.11	80.04	79.71	80.04
19.25	13.87	14.04	13.73	13.33	13.73
6.11	4.86	5.89	5.08	5.86	5.08
.60	.37	.59	.52	.40	.40
100.00	100.00	100.00	100.00	100.00	100.00

RADICLES IN GRAMS PER LITER.

	K.....	Na.....	Ca.....	Mg.....	Cl.....	Br.....	SO ₄
1.7	3.5	65.1	31.9	6.9	176.9	1.7	286.0
37.7	33.2	46.9	46.9	11.1	202.9	1.6	286.9
22.8	45.7	45.7	10.3	128.7	2.2	322.9	286.0
9.5	3.7	3.7	154.1	154.1	1.6	210.1	286.0
124.6	128.7	128.7	154.1	154.1	1.6	210.1	286.0
1.3	.3	.3	.7	.7	.3	210.1	286.0
1.7	.1	.1	.7	.7	.3	210.1	286.0
198.3	286.0	286.0	286.0	286.0	286.0	286.0	286.0
Summation.....	198.3	286.0	286.0	286.0	286.0	286.0	286.0

CONVENTIONAL COMBINATIONS IN GRAMS PER LITER.

KCl.....	3.3	6.6	6.1	4.9	1.7	1.3	1.8	1.8	2.1	0.6	0.6	0.6	0.4
NaCl.....	93.2	162.8	88.9	146.5	154.4	188.3	221.5	244.3	182.5	72.0	75.8	84.0	56.2
CsCl.....	62.7	88.4	120.0	123.6	38.3	42.2	23.2	44.1	107.2	12.1	13.2	14.9	15.6
Cs ₂ SO ₄	1.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
MgCl ₂	36.7	26.3	42.9	39.4	14.5	15.8	12.3	16.8	34.2	5.3	4.8	6.1	5.2
MgBr ₂	1.4	1.9	1.8	2.5	.7	.8	.4	.8	2.0	.4	.5	.4	.5
Summation.....	198.3	286.0	269.9	322.9	210.1	249.4	260.2	308.0	328.2	90.4	94.9	106.2	80.9

* Blank spaces indicate that a trace of SO₄ was present but not determined.

NOTE.—Iron, alumina, silica, etc., not determined. Iodine was not looked for. Qualitative test showed presence of bromine in all the samples.

2. Ohio Salt Co., Pittman, Ohio.
3. Colonial Salt Co., Kenmore, Ohio.
- 4a. Chas. B. Apple, Lakewood, Ohio.
- 4b. Chas. B. Apple, Lakewood, Ohio.
5. Saginaw Salt Co., St. Charles, Mich.
6. Saginaw Salt Co., well 2, St. Charles, Mich.
- 7a. Saginaw Salt Co., well 2, St. Charles, Mich.
- 7b. Saginaw Salt Co., well 2, St. Charles, Mich.
8. Struble Lumber Co., Saginaw, Mich.
9. Hine Lumber Co., Bay City, Mich.
11. Midland, Mich.
13. Ohio River Salt Co., Mason City, W. Va.
14. Excelstor Salt Co., Pomeroy, Ohio.
15. Pomeroy Salt Association, Pomeroy, Ohio.
16. Liverpool Salt & Coal Co., Hartford, W. Va.
17. J. Q. Dickinson, Malden, W. Va.

COMMENTS ON THE INDUSTRY.

The usual type of bromine plant, one involving salt wells and salt-making apparatus, has survived in the United States only by virtue of exceptional economic conditions. Cheap coal or other fuel and distance from competing centers have doubtless been factors.

Bromine is made from natural brines that are not of the same purity as the artificial brines, so called, from which salt is made in New York, northern Ohio, and along the Detroit and St. Clair Rivers in Michigan. The natural brines are not so saturated as those obtained by dissolving rock salt, hence they require more heat for evaporation. In places the evaporating apparatus for natural brine has also involved the use of copper and brass instead of iron, which is used in the evaporating equipment for artificial brines. For these reasons and others competition with salt made from rock salt has in the course of years grown more severe, and the salt and bromine industry along the Ohio and Kanawha Rivers and in the Saginaw Valley has steadily diminished.

Without doubt, under the conditions existing before the war in Europe began, there was an oversupply of bromine readily available in the world's market, and prices were so low that certain bromine manufacturers were compelled to store their product to wait for higher prices.

Much bromine is found in connection with the potash salts deposits at Stassfurt, Germany. The bromine is said to occur in the form of brom-carnallite ($\text{MgBr}_2 \cdot \text{KBr} \cdot 6\text{H}_2\text{O}$) isomorphous with ordinary carnallite. Although the German deposits furnish more than half of the world's supply of this commodity, much German bromine has gone to waste and new uses have been urgently sought for it. The sum of \$2,500 has been offered by the Deutsche Bromkonvention Gesellschaft, Leopoldshall-Stassfurt, to the discoverer of a process or compound leading to a new or increased consumption of bromine. The terms of the reward were that the discovery should represent a technical innovation and not adversely affect existing uses of bromine. The process should also lead to a considerable increase in the European consumption of bromine.^a

Bromine manufacture in the United States has undergone many spectacular changes since the European war began. Before the war low prices of bromine had compelled some manufacturers to store their product. When the supply of bromine from Germany, and especially the supply of bromides, was cut off, the domestic facilities could not supply the American demand, and prices soared. In a comparatively short time conditions changed, and this country without doubt can now supply its own requirements.

^a Journal of Industrial and Engineering Chemistry, Wanted: New uses for bromine, vol. 5, September, 1913, p. 780.

While the demand was greatest, many new producers entered the field, and as a result there were adjustments in the industry. Now the effects of the larger facilities are being felt. Most of the smaller concerns that entered the industry at the beginning of the war have been well paid, however, for their trouble. Most of the changes in the industry have taken place in the Saginaw Valley, Mich., one of the few important bromine-producing fields in the United States.

One of the readjustments since the war broke out is that of the many plants making salt in the vicinity of Saginaw, Mich.; a few firms only now make bromine. These buy all the mother liquor procurable from the salt concerns that do not utilize it. Thus the manufacture of bromine and calcium chloride from the mother liquor is now carried on at a comparatively few plants and the mother liquors, such as were largely wasted four or five years ago, are now all being utilized.

METHODS OF MAKING BROMINE.

Bromine forms chemical compounds in natural brines, but is present only in small proportion, as the table of analyses on page 82 indicates. In these brines it is always associated with other salts, the principal ones being the chlorides of sodium, magnesium, and calcium. Generally bromine is obtained from the mother liquors that result from the crystallization of salt from brines, but at Midland and Mount Pleasant, Mich., the Dow Chemical Co. extracts bromine from unconcentrated brine.

There are at least three standard methods employed in making bromine. At least two, and possibly the entire three, are now in use in the United States. They are known as (1) the periodic or intermittent process, (2) the continuous process, and (3) the electrolytic process.

PERIODIC OR INTERMITTENT PROCESS.

The periodic or intermittent process of making bromine is in use along the Ohio River in Ohio and West Virginia, at Malden, W. Va., and at Bay City, St. Charles, and Saginaw, Mich. The standard practice along the Ohio River may be taken as typical.

PRODUCTION OF BROMINE IN OHIO AND WEST VIRGINIA BY INTERMITTENT PROCESS.

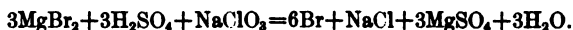
In southern Ohio and West Virginia, after the removal of the bulk of the salt in the main grainers, the bittern in the last grainer is further concentrated to the strength desired for entry to the bromine still—usually to 39° to 41° B. (specific gravity, 1.370 to 1.397 at its highest temperature).

The bromine still is made of sandstone. Though a local sandstone is used at one plant, a sandstone from Buena Vista, near Portsmouth, Ohio, seems to be in general use, and it is said to be practically free

from iron oxide and of close texture, a combination of chemical and physical properties that well adapts it for the purpose. Stills are built in various ways. Some consist of cubical or rectangular blocks hollowed out and placed together edge to edge, so that the hollow parts form a single interior chamber, and some are built up of sandstone rings, 6 inches or more thick, clamped together and cemented with acid-resisting and bromine-resisting material like asbestos or white lead and cotton. The top and bottom slabs are usually the thickest. Holes in the top slab admit the brine and the chemicals. The working capacity of the stills ranges from 400 to 1,200 gallons of liquid.

Sodium chlorate and sulphuric acid of 66° B. are used in liberating the bromine from the bittern. Formerly manganese dioxide and sulphuric acid were used and later potassium chlorate and sulphuric acid. Comparison of the molecular weights of potassium chlorate (123) and sodium chlorate (107) shows that the latter compound is a more efficient oxidizing agent than the former, weight for weight, without reference to the lower price of the sodium compound, which is now used almost exclusively. Some firms use 60° sulphuric acid, which costs less than the 66° acid. The readiness, however, with which the more dilute acid attacks iron, especially the iron tanks used to transport it, has caused the more concentrated acid to displace it almost completely.

After the bittern enters the still and the requisite amounts of sodium chlorate and sulphuric acid are added, a jet of steam is discharged into the solution. As the temperature rises, a reaction, approximately represented by the following equation, takes place:



The bromine set free passes from the still as a gas. But the reactions are more complex than the equation indicates, for some chlorine is liberated and passes from the still with the bromine. The latter is freed from chlorine by passing through washers filled with milk of lime $[\text{Ca}(\text{OH})_2]$, which forms, with the chlorine, calcium chloride (CaCl_2) and calcium hypochlorite $[\text{Ca}(\text{OCl})_2]$. Some bromine is taken up by the lime but is recovered later. The bromine distilled goes to a condenser. This is a rectangular box about 5 feet long, through which three lead pipes extend from the still to three glass collecting bottles in series, sealed to one another and to the worm with mud or clay. Any bromine that passes the last bottle is caught in towers 6 to 8 feet high and 2 or 2.5 feet in diameter made of sewer pipe and filled with coke. Any bromine water that collects in them runs out at their base. The bromine caught beyond the first bottle is usually rather dilute, and may be returned for further distillation. About 35 pounds of bromine is obtained from 700 gallons of bittern

having a strength of 40° B. The amounts of sodium chlorate and sulphuric acid necessary depend largely on the concentration of the bittern.

DISTILLATION OF BROMINE IN MICHIGAN.^a

The old practice in Michigan did not differ fundamentally from that described above. After the bulk of the salt has been removed in the grainers, the bittern or mother liquor containing the more soluble salts in the form of calcium and magnesium chlorides, bromides, and iodides is run into other tanks or grainers, where it is further concentrated to a specific gravity of 30° or 31° B. Of course, salt separates in these grainers, after which the liquor is ready for the bromine stills.

The boiling bittern is run into sandstone stills having a capacity of 400 to 1,000 gallons, and treated with dilute sulphuric acid and sodium or potassium chlorate, which produces free chlorine, which in turn liberates the bromine from its combinations.

Formerly manganese dioxide was used in the place of chlorate, as was also true along the Ohio River, but it has been discarded for economy and ease of handling. Most of the Michigan makers of bromine in recent years have employed sodium chlorate instead of potassium chlorate for the reason already given—its producing more bromine per pound.

The bittern in the still is kept boiling by the continuous inflow of steam, and the bromine is blown out by the same means. The bromine vapor and water coming from the still are condensed in lead pipes running through cold water contained in a rectangular box 5 to 6 feet long and 3 feet deep.

The lead condenser has always been objectionable, as it requires frequent renewal at considerable expense. The writer was told that the lead coils are serviceable for 30 to 50 runs. Provided a still holds 500 gallons per run, a lead coil would serve at the maximum for distillation of fifty times 500 gallons, or 25,000 gallons of liquid. The bromine made in such lead coils, moreover, is apt to be contaminated, as the bromine attacks lead. There has been a tendency to replace lead coils with hollow earthenware disks and coils of the same material. These work perfectly and tend to preserve the purity of the bromine. They are somewhat fragile, and those that are of foreign make are not readily procurable, especially at present (1916). The lead coils in common use are not nearly as long as the earthenware coil, but this drawback appears not to be insurmountable. Lead worms seen by the writer were 16 feet long, whereas the earthenware worms were 40 feet.

The bromine is collected in stoneware receivers and is separated from the accompanying water. If it is not up to the standard of the

^aDiehl, O. C., The technology of bromine: Mineral Industry during 1906, vol. 17, 1909, pp. 92-94.

United States Pharmacopœa, which calls for 97.6 per cent bromine, it has to be brought up to this standard by any proper means. It is marketed in bottles holding $6\frac{1}{2}$ pounds. The process outlined above is not in use either at Midland or Mount Pleasant, according to the writer's present information.

DRAWBACKS TO PERIODIC PROCESS.

According to the common chemical method of making bromine, described above, the mother liquor or bittern obtained from concentrating the natural brine and removing the salt from it, is boiled with an acid and oxidizing agent to liberate the bromine. The bromine and steam are then condensed, and the former separates by virtue of its specific gravity and its insolubility in water.

This method of bromine manufacture is costly because of the great volume and weight of the solution from which the desired end product is distilled. Moreover, large apparatus is required to handle the liquor and considerable heat for distillation. Other drawbacks to the chemical method are loss of time and materials and a rather low efficiency, the recovery of the bromine present in the original brine from the mother liquor being only 60 per cent.

RECENT DEVELOPMENTS IN PREPARING BROMINE.

Recent patents outline methods of preparing bromine by oxidation reactions similar to those employed in the ordinary chemical processes that have been described. However, the methods of producing the original bromides or bromates are not given, but they may be made by the continuous process subsequently described.

Barstow ^a has devised a process in which the liberated bromine is separated by gravity from the accompanying solution. A strong solution of the bromide and bromate is made up, sodium bromide and either sodium or potassium bromate being usually employed.

The bromide and bromate are generally used in proportions of 5 of the former to 1 of the latter, as indicated in the reaction below. The prepared solution is run into a cement-lined tub having a cement-covered agitator and a lead worm. Sulphuric acid is added slowly; the solution is agitated and the temperature is kept low by means of the cooling coil, but above the crystallizing point of the sodium sulphate formed. Enough acid is added to combine with the bases present, as indicated by the reaction.



The bromine precipitates as a heavy liquid which is only slightly soluble in the strong sulphate solution. After all the acid required

^a Barstow, E. O., U. S. Patent No. 1141922, June 8, 1915, assigned to the Dow Chemical Co., of Midland, Mich.

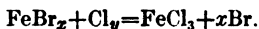
has been added, the solution is cooled substantially to the crystallizing point of the sulphate. The bromine collects on the bottom of the container and may be drawn off from beneath the sulphate solution. It has been found that where sodium bromide, sodium bromate, and sulphuric acid are used, about 95 per cent of the bromine in the bromide and bromate may be drawn off as liquid bromine, only a small quantity remaining dissolved in the sulphate solution. The traces of bromine that remain in the solution may be recovered, if desired, by blowing them out with a current of air and absorbing them in an alkali solution.

It is thus possible to obtain the desired product, namely, liquid bromine, as a direct result of a single reaction involved in the process. This is accomplished without any wasteful expenditure of heat, in the form of steam, and at the same time it does away with the necessity for handling hot bromine vapors, which are both corrosive and very unpleasant to deal with.

Barstow^a has devised another and different process of preparing bromine.

In this process a strong iron bromide solution is used, and obviously, the bromine occurring in the natural brines, magnesium bromide, sodium bromide, etc., must be converted into iron bromide by any of the usual methods before the process may be employed.

Figure 3 shows a diagram of the apparatus. The strong iron bromide solution is fed into the top of a tailings tower, 1, the solution being supplied from a tank, 2. After descending through the tailings column the solution passes through a condensing coil, 3, thence through a reaction column, 4, in which it meets a rising stream of chlorine gas supplied from a gas main, 5. The chlorine reacts with the iron bromide, forming iron chloride and liquid bromine in accordance with the following reaction, in which the values of x and y vary with the relative proportions of FeBr_2 and FeBr_3 in the iron bromide solution:



A strong iron chloride solution and liquid bromine are thus produced, the latter being only sparingly soluble in the former. Some heat is generated in the reaction, which may vaporize part of the bromine, but the bromine vapors will be condensed in the condenser 3 and flow back into the column 4. If a small quantity of bromine vapor be carried through by the air that may be intermingled with the chlorine, it will be absorbed in the tailings tower 1 by the fresh iron bromide solution entering from tank 2, as such solution usually contains some ferrous bromide, for the reason that the strong ferric bromide solution is a good mechanical absorber of bromine, and the

^a Barstow, E. O., U. S. Patent No. 1141921, June 8, 1915, assigned to the Dow Chemical Co., of Midland, Mich.

ferrous bromide present is an active chemical absorbent. The bromine is thus kept from escaping from the system, and any air fed into the reaction column with the chlorine escapes through the

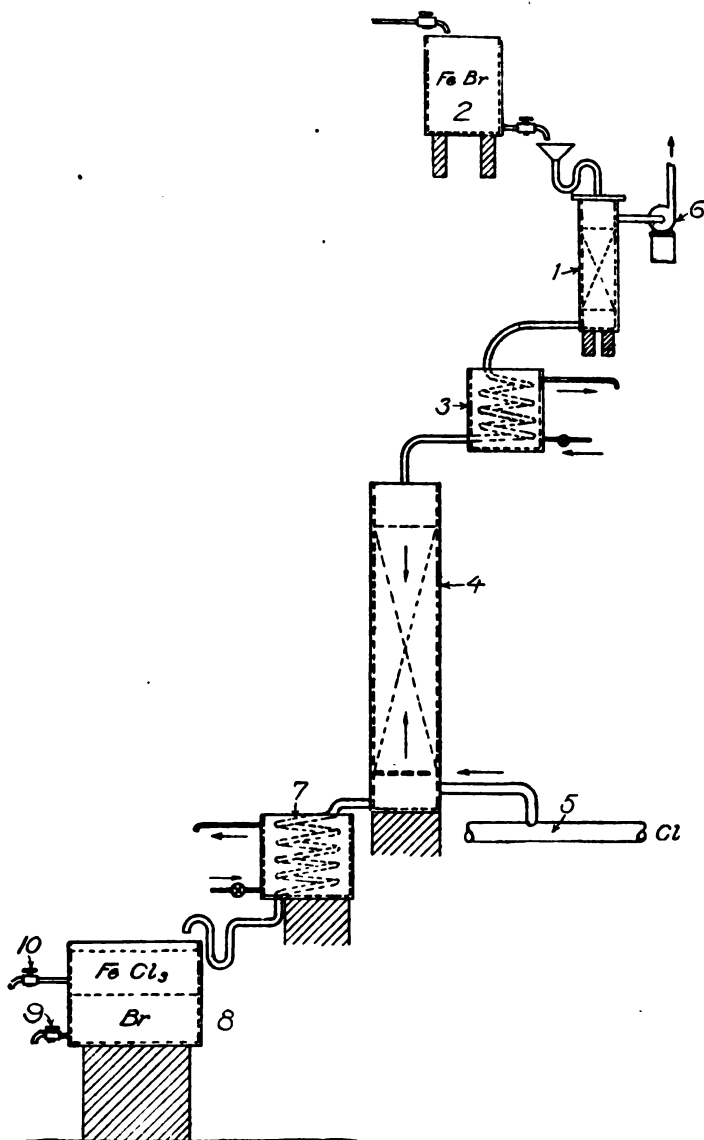


FIGURE 3.—Apparatus for producing and separating bromine without distillation.

exhauster 6 that maintains the flow of chlorine upwardly through the reaction column 4. The mixture of strong iron chloride and liquid bromine flows downward through the reaction column and from it through a cooling worm 7 to a container 8, where the bromine sepa-

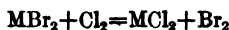
rates by gravity from the iron chloride solution. On account of the greater specific gravity of the bromine it sinks to the bottom, and the separation of the two liquids is sufficiently perfect to make it possible to draw them off by two separate spigots 9 and 10. The bromine obtained usually contains considerable chlorine, which is removed by agitation with a bromide solution, preferably iron bromide, such as is used in the principal reaction. A small part of the bromine, moreover, will remain dissolved in the iron chloride solution, but this may be removed, if desired, by throwing it out with a blast of air and absorbing it in any suitable way, for example, with a solution of ferrous bromide.

The process described does not require any steam and obviates handling hot bromine vapors, which are both corrosive and unpleasant to deal with. When a sufficiently strong solution of iron bromide is used it has the further advantage of producing a solution of iron chloride with a specific gravity of 35° B., or more, which is an article of commerce. If the bromine were separated by the usual processes of injecting live steam, the chloride solution would be so dilute as to require concentration before becoming available for sale or for ordinary commercial use.

CONTINUOUS PROCESS.

The disadvantages outlined under the intermittent method of making bromine have led to the adoption of what is usually known as the continuous process, a chemical as contrasted with the electrolytic method, in which the electric current sets free the bromine. In the continuous process chlorine gas is the agent used to liberate the bromine from its combinations, and the chlorine may be made by any convenient means, for example, by electrolysis of a pure or impure sodium chloride solution, or by combining such chemical compounds as will produce chlorine, for example, bleaching powder and sulphuric acid.

The chlorine gas that is produced in standard cells of different types, or by other means, is passed through the bromine-bearing brine. The bromine is liberated according to the simple reaction .



in which M stands for metal, leaving the bromine mechanically held in the solution. The bromine is recovered from its solution in the brine by air currents brought into contact with it. The bromine-laden air is then brought into contact with such substances as will readily form a chemical combination with it. Iron may be used, a solution of ferric bromide being formed. If a solid is desired, ferrous bromide may be made from the ferric salt by suitable means.

A remarkable series of patents have been taken out by Herbert H. Dow, of the Dow Chemical Co., of Midland, Mich., relating to the preparation of bromine by the continuous process.

The series of patents begins with one describing a "process of extracting bromine," No. 460370, dated September 29, 1891, and a reissue patent No. 11232, dated April 12, 1892, with the same title. These two patents will be briefly outlined.

Many salt wells, especially in Saginaw Valley, will not pay when worked for salt alone, owing to the low price for that commodity. When the brine from such salt wells is rich in bromine, it is of considerable commercial importance to be able to extract it cheaply without incurring the expense of evaporating the brine. The process described, however, is applicable to bitter waters after the salt has been removed from them.

Electricity, chlorine gas, or a combination of compounds that will produce chlorine gas, for example, bleaching powder and sulphuric acid, may be employed to liberate the bromine left in solution in the brine.

The bromine is recovered after liberation from the brine by air currents which drive it out. The bromine-laden air is then brought into contact with any substance that will chemically combine with the bromine, for example, iron turnings or filings. Ferric bromide forms, which with the moisture absorbed from the air forms a solution. If a solid is desired, ferrous bromide (which is a more stable compound when heated) may be formed by bringing the solution of ferric bromide into contact with iron and evaporating to dryness in a vessel from which air is excluded by steam. Other metals may be substituted for iron when other bromides are desired, and other gases, for example natural or artificial gas, may be substituted for air for driving the bromine from its solutions.

The brine may be treated electrolytically in tanks or chlorine may be forced through it, either in the form of a gas as such or the chlorine may be formed by the interreaction between bleaching powder and sulphuric acid in the brine itself. The brine containing the bromine is drawn off into shallow tanks placed near the upper part of a closed space or room. The tanks are provided with a series of drip holes from which the brine showers down on sheets of burlap stretched on frames in an inclined position. Wooden surfaces may be used instead of the burlap. A blower sucks air through the descending solution containing the bromine in such a way that fresh air comes in contact with the solution most depleted of its bromine. Thus all the bromine is removed from the solution, and the air as it passes on comes in contact with brine richer and richer in bromine. The air passes off through a duct, then through the bottom of a container which is partly filled with iron turnings or scrap iron, with which the

bromine unites to form ferric bromide. With the moisture there is formed a solution of the ferric bromide, which drops through a spout into a suitable stone container. The air from which the bromine is freed is again used, and so the process goes on. The lower floor of the apparatus is inclined so that the spent brine flows away through a trap and no air is wasted.

These first patents were followed by others, which involve modifications and improvements, or relate to closely allied operations, such as the manufacture of bromides. Later patents are as follows:

Process of extracting bromine from brine; No. 714160, November 25, 1902, issued to Herbert H. Dow, assignor to the Dow Chemical Co., of Midland, Mich.

Process of manufacturing bromine; No. 733466, July 14, 1903, issued to Herbert H. Dow.

Process of manufacturing bromides from bromine-containing solutions; No. 733467, July 14, 1903, issued to Herbert H. Dow.

Process of extracting bromine from brine; No. 741637, October 20, 1903, issued to Herbert H. Dow, of Midland, Mich., assignor to the Dow Chemical Co., of Midland, Mich.

Process of fractioning bromine apart from chlorine; No. 752286, February 16, 1904, issued to Herbert H. Dow, assignor to the Dow Chemical Co., of Midland, Mich.

Process of fractioning bromine from chlorine; No. 752331, February 16, 1904, issued to Herbert H. Dow, assignor to the Dow Chemical Co., of Midland, Mich.

Process of manufacturing bromine from natural brines; No. 752332, February 16, 1904, issued to H. H. Dow, assignor to the Dow Chemical Co., of Midland, Mich.

Method of converting bromine into bromides and bromates; No. 765417, July 19, 1904, issued to H. H. Dow, assignor to the Dow Chemical Co., of Midland, Mich.

Process of manufacturing bromides; No. 997972, July 18, 1911, issued to H. H. Dow, assignor to the Dow Chemical Co., of Midland, Mich.

Other patents relating to the preparation of bromine or halogen compounds, among which bromides are included, are as follows:

Method of making haloids; No. 964156, July 12, 1910, issued to James C. Graves and John P. Simons, assignors to the Dow Chemical Co., of Midland, Mich.

Method of making halogens; No. 1036121, August 20, 1912, issued to Coulter W. Jones and Arthur E. Schaefer, assignors to the Dow Chemical Co., of Midland, Mich.

Process for the recovery of bromine; No. 1085944, February 3, 1914, issued to Arthur E. Schaefer, of Saginaw, Mich.

Method of extracting bromine; No. 1188838, June 27, 1916, issued to Arthur E. Schaefer, assignor to the Dow Chemical Co., of Midland, Mich.

In this connection, two patent specifications issued to Herbert H. Dow and relating to electrolytic cells are of interest. These are as follows:

Porous diaphragm for electrolytic cells and method of producing same; No. 621908, March 28, 1899.

Method of and apparatus for electrolyzing liquids; No. 1100290, June 16, 1914.

ELECTROLYTIC PROCESS.

The electrolytic process for making bromide depends on the principle that bromides decompose at a lower voltage than chlorides and

hence are first decomposed by the electric current. Notwithstanding that the reaction is carried only far enough to liberate the larger part of the bromine, it always results in the production of some chlorine which subsequently has to be eliminated. Diaphragm cells may or may not be used. A weak current is used—not more than 4 to 5 volts. It is not known whether the process is used in the United States, but it probably is. Owing to the low concentration in bromides and the large bulk of liquor generally handled, and also to the formation of bromates and chlorates, the efficiency is low.

One method of carrying on the process is as follows: The brine is run into long wide wooden vats in which carbon electrodes are introduced and in which the electrolysis takes place. The solution containing the bromine trickles continuously over a lattice work down a tall wooden tower, upward through which passes a strong air current. The bromine vapor is then passed through water and an aqueous solution is formed. The aqueous solution then trickles downward through another tower built of bromine-resisting material such as sewer pipe. In this tower are coils of thin iron ribbon or wire. The iron combines with the bromine, forming bromide of iron. This compound is next treated with sodium, potassium, or ammonium hydroxide, depending upon the bromide desired. This mixture is boiled down in cylindrical iron tanks, and after the reaction is completed the precipitated ferric hydrate is filtered off and the clear solution further concentrated until the bromides crystallize out. These are dried over steam coils or in any other suitable manner.

According to Blount and Bloxam,^a "Bromine is now also obtained from the Stassfurt residues by electrolyzing the liquors between carbon electrodes in open vessels, through which the liquid is passed at a certain rate. Up to 30 secondary carbon electrodes are placed in the vats, which practice permits a current of 90 volts to be used. This is found to give the maximum efficiency. The bromine liberated remains dissolved as such in the liquid and is separated at a subsequent distillation.

"The crude bromine contains chloride of bromine and generally lead bromide and hydrocarbons, the latter being derived from tar joints. It is shaken with potassium bromide to decompose the bromine chloride, and distilled in glass retorts."

USES OF BROMINE.

Bromine is used in the manufacture of certain coal-tar dyes such as the brom eosins, also in the manufacture of such bromides as potassium bromide, sodium bromide, ammonium bromide, and strontium

^a Blount, B., and Bloxam, A. G., *Chemistry for Engineers and Manufacturers*, 1910, p. 459.

bromide. It is also used as a reagent in analytical chemistry and in the manufacture of certain organic bromides. The latter are used in photography and in medicine.

Bromine has also been used in extracting gold from its ores and in refining platinum, and in connection with the manufacture of Prussian blue and potassium permanganate. It is also a disinfectant. It is reported to have been used in the present war in the asphyxiating mixtures used in the trenches, its effects being reported to be most disastrous, and burns from bromine severe.

It is considered dangerous freight by the transportation companies, and it sometimes appears in the form of "solidified bromine," patented by Frank. This consists of sticks of diatomaceous earth made plastic with size or molasses and then pressed into sticks of $\frac{1}{4}$ -inch or $\frac{1}{2}$ -inch diameter, which are dried or burned till coherent, but not to the degree of losing their porosity. They are then soaked in liquid bromine contained in wide-mouthed, stoppered, glass bottles. The porous material absorbs 50 to 75 per cent of its weight of bromine, after which the excess liquid bromine is poured off. The sticks are sold in the same bottles. Bromine in this form may be used conveniently as a certain number of sticks represent a given weight of the substance, and the necessity for weighing the liquid itself is thus obviated.

RECOVERY OF CALCIUM CHLORIDE.

Under this heading is considered only calcium chloride that is produced in connection with the manufacture of salt and bromine from natural brines. The waste calcium chloride so largely produced in connection with the ammonia soda process at Solvay, N. Y.; Wyandotte, Mich.; Barborton and Fairport Harbor, Ohio; Hutchinson, Kans.; and Saltville, Va., is not considered, for such calcium chloride derives its base from limestone and its acid from common salt, and it is not, as such, an original constituent of the brine.

OHIO AND WEST VIRGINIA.

In the chemical process of making bromine the bittern from the bromine stills goes directly to the calcium chloride plant. Here it is generally first neutralized with lime and allowed to settle as long as necessary; it may go to a rectangular vat for further concentration. After having settled it is run to the kettles for final evaporation. The kettles are cylindrical with conical bases fitted with steam coils; some also being provided with steam jackets through which live steam is passed. The liquor is boiled in them to the consistency of a thick sirup. A plug is then drawn from the bottom of the kettle

and the thick liquid is run into metallic drums, in which it solidifies on cooling. It is then ready for market.

Analyses of the brines are shown in the table on page 82.

MICHIGAN.

When bromine is not recovered from the mother liquor resulting from the extraction of salt, as was the case formerly at certain plants before the recent demand caused by the European war sprang up, such mother liquor is directly evaporated for its saline content.

After the salt has been separated in the main grainers and the latter are ready to be cleaned, the bittern is further concentrated in another grainer or set of grainers to a specific gravity of 30° or 31° B. Of course, salt separates in this second set of grainers, after which the bittern goes to the calcium chloride works. Here the bittern is further concentrated to a strength of 45° B. The volume of this concentrated bittern is about 8.5 per cent of that of the original brine. The composition of this strongly concentrated liquor while at the boiling point is as follows:

Composition of calcium chloride liquor.

Calcium chloride (CaCl_2).....	34.50
Magnesium chloride (MgCl_2).....	11.60
Sodium chloride (NaCl).....	None.
Water.....	53.90
	100.00

At Mount Pleasant the liquor from which the bromine has been recovered goes to the storage tanks of the salt block, where it is heated and agitated with milk of lime. After this operation ceases the suspended matter quickly settles, leaving a clear supernatant liquid above, which is evaporated in a modified form of open pan. After partial separation of the salt, the bittern is concentrated in another pan to 42° to 44° B. and is then run into a settling tank, where the rest of the salt settles out. The bittern is then boiled in a cauldron until all the water has been evaporated except that necessary for crystallization of calcium chloride. The liquid is then run into metal drums of 700 pounds capacity, where it solidifies, and in this form it is placed on the market. The liquid may be run in a viscous condition onto floors over which cold water is circulated in pipes. The sudden solidification produces a tension in the calcium chloride, and it may be readily broken by sledge hammers. It is passed through a rotary crusher, sized, and barreled for the trade.

Analyses of the product at different plants are as follows:

Analyses of calcium chloride obtained from natural brines in Michigan, Ohio, West Virginia, and Pennsylvania.

RADICALS IN PERCENTAGE OF TOTAL WEIGHT.

Constituent.	1	2	3	4	5	6	7
K.....	0.7	0.8	Trace.	Trace.	0.3	0.2	Trace.
Na.....	.6	2.4	3.7	Trace.	.0	.1	None.
Ca.....	19.5	19.6	18.5	24.6	18.9	18.4	30.4
Mg.....	4.9	5.1	5.3	5.3	4.6	3.4	1.8
Cl.....	50.4	53.9	53.9	62.0	43.9	42.6	59.0
SO ₄	None.	None.	None.	1.6	None.	None.	Trace.
CO ₂.....	.....	.....	.....	.....	.6	.3	.....
Br.....	.....	None.	Trace.	None.	1.1	None.	None.
	76.1	81.8	81.4	94.5	69.8	64.7	91.4

CONVENTIONAL COMBINATIONS IN PERCENTAGE OF TOTAL WEIGHT.

KCl.....	1.4	1.5	Trace.	Trace.	.6	.4	Trace.
NaCl.....	1.6	6.1	9.4	Trace.	.0	.3	None.
CaCl ₂	53.9	54.2	51.2	68.3	51.4	50.6	84.2
MgCl ₂	19.2	20.0	20.8	24.4	17.2	13.3	7.0
CaSO ₄	None.	None.	None.	2.2	.9	.5	Trace.
MgSO ₄	None.	None.	Trace.	None.	1.3	None.	None.
Water by difference.....	23.9	18.2	18.6	5.1	29.6	34.9	8.8
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

^a CaCO₃.

1. Eureka Calcium Works, Pomeroy, Ohio, 1911. R. F. Gardiner, analyst.
2. Liverpool Salt & Coal Co., Hartford, W. Va., 1911. R. F. Gardiner, analyst.
3. Hartford City Salt Co., Hartford, W. Va., 1911. R. F. Gardiner, analyst.
4. J. Q. Dickinson & Co., Malden, W. Va., 1911. J. A. Cullen, analyst.
5. Saginaw Chemical Works, Saginaw, Mich. Traces of barium and strontium, 1911. R. F. Gardiner, analyst.
6. Van Schaack Calcium Works, Mount Pleasant, Mich., 1911. R. F. Gardiner, analyst.
7. Pittsburgh Calcium Chloride Works, Pittsburgh, Pa., 1911. R. F. Gardiner, analyst.

In this connection, the magnesium chloride content is of interest and importance.

The bromine content of the sample collected at the Saginaw Chemical Works, Saginaw, Mich., points to the nonremoval of the bromine after the crystallization of the salt and before evaporation to produce the final product. It should be noted that the samples whose analyses are given above were collected in 1911.

VACUUM-PAN PROCESS.

HISTORY.

On July 16, 1839, John Reynolds in English Patent No. 8155, outlined a process for improving the manufacture of salt by "causing the steam produced by boiling brine or salt water in a closed vessel to transfer its heat to and thereby boil brine or salt water in a second closed vessel, so that the steam from such second closed vessel may in like manner transfer its heat to brine in a third vessel, and so on, by maintaining in each of a series of closed vessels in which brine is subjected to evaporation such relative pressure as will cause the

respective boiling points of the brine contained in each to be lower from the first to the last of the series, so that the steam or vapor produced from the brine in each vessel may be condensed in a vessel of thin metal immersed in the brine of the next succeeding vessel. The graduations of pressure may be obtained either by diminishing a pressure superadded to that of the atmosphere, or by diminishing the pressure of the atmosphere alone."^a

The principle of multiple effect evaporation, however, does not appear to have begun with the evaporation of brine for salt. A catalogue issued by the Zaremba Co., of Buffalo, N. Y., states that:

Vacuum pans were first used in 1813 in the form of single effects in the manufacture of sugar. These single effects comprised a single evaporator body consisting of a closed vaporizing element connected with a condenser and air pump, the heating element consisting of coils of piping submerged in the liquor. The liquor was subjected to but one ebullition in a given evaporator, hence the name "single effect." Here the theoretical efficiency was 1 pound of water evaporated per pound of steam used.

The second great step in evaporator development took place in 1830, when Rilleaux broached the idea of multiple effect evaporation, in which, as a result of performing several ebullitions under varying degrees of vacuum, the amount of work done by the steam is greatly augmented. He experienced great difficulty in introducing his improvement, so much so that it took 30 years to bring it into general use in European sugar factories.

So far as known, the first vacuum pan used in the United States for the manufacture of salt was started by Joseph M. and John H. Duncan, brothers, in the spring of 1885 at Warsaw, N. Y.

In the fall of 1880 the Duncan brothers were sent by the American Dairy Salt Co., of Syracuse, N. Y., to investigate salt-making machinery used in the East. The Duncans were particularly interested in the centrifugals and driers used in sugar manufacture, especially with reference to their possible adaptability for drying salt that came from the washing machines then in use. At that time all dairy salt was washed in machines with a solution of brine and soda ash to remove impurities.

The Duncans became greatly interested in the vacuum pans used in making sugar; but on being informed that it was impossible to crystallize the sugar in the pans, the subject was dismissed for the time being until it occurred to them that vacuum pans might be used in strengthening the weak brines of the Onondaga Indian Reservation. On further investigating the subject, it was concluded that the project was not practicable and the subject was dropped.

In 1883, Joseph M. Duncan left Syracuse to become manager of the Warsaw Salt Co., Warsaw, N. Y., where he erected and operated a large plant. After this plant had been placed in operation, experiments with vacuum pans in salt manufacture were again taken up,

^a Thorpe, Edward, Dictionary of applied chemistry, vol. 5, 1913, pp. 12-13.

the strong brines at the Warsaw plant being used. An experimental pan, about 4 feet in diameter, was built along the same lines as are many of the vacuum pans in present-day use. Considerable trouble was experienced in crystallizing the salt, but after many experiments, success was achieved and the first salt made in a vacuum pan was produced. In the meantime, patents had been applied for.

Joseph M. Duncan later left Warsaw, and the brothers organized the Duncan Salt Co. and in 1885 took over the plant of the Silver Springs Salt Co. at Silver Springs, N. Y. During 1886 or 1887 they constructed a vacuum pan 7 feet in diameter. This was the first commercial vacuum pan constructed for the manufacture of salt. It was a success from the start, so far as the production of salt was concerned, but great difficulty was experienced with the salt and gypsum that so coated the tubes that they required boiling and boring out every few hours at great expense. This discouraging feature was gradually overcome as the Duncans became better acquainted with the brine and the proper treatment necessary to avoid these difficulties.

Their experience led them to design a pan with the tubes in sections, so that steam could be used on the inside of the tubes and the brine outside. This new type of pan gave better efficiency than the older pans and could be more readily cleaned. It also produced a much harder grained salt. However, the hard, small grain of the salt made difficult the marketing of the product. It received the name of "musical salt," for when put up in packages it gave forth a musical sound when the package was twisted, owing to the hardness of the crystals. Though small, the crystals were perfect cubes, and in hardness and shape were quite different from the crushed or ground salt then on the market.

The Duncan brothers were also the first to employ the centrifugal principle for drying salt. In their plant at Silver Springs the bottom of their vacuum pan was constructed with a series of valves, so that the salt could be drawn directly from the pan into the centrifugal without the aid of an elevator or other machinery. This method of production gave their product a reputation for cleanliness. The Worcester Salt Co., of Silver Springs, N. Y., formed by the union of the Duncan Salt Co. and the Nash-Whiton Co., employ pans of the sectional type.

The R. G. Peters Salt Co., of Manistee, Mich., so far as known, were the first to employ the vacuum pan in making salt in Michigan.

PRODUCTION CENTERS.

The vacuum-pan process is used in nearly all districts of the United States in which much salt is produced by evaporation. It is used in New York at Silver Springs, Ithaca, Ludlowville, and Watkins. In

Michigan salt is made by the vacuum-pan process at Del Ray, Wyandotte, and Ecorse, south of Detroit, and along St. Clair River at Port Huron, St. Clair, and Marine City, as well as at Ludington and Manistee and its suburbs in the western part of the Lower Peninsula. It is also used at Kenmore, Wadsworth, Cleveland, and Rittman, Ohio, Hutchison, Kans., and near San Mateo and Alvarado and in San Francisco, Cal.

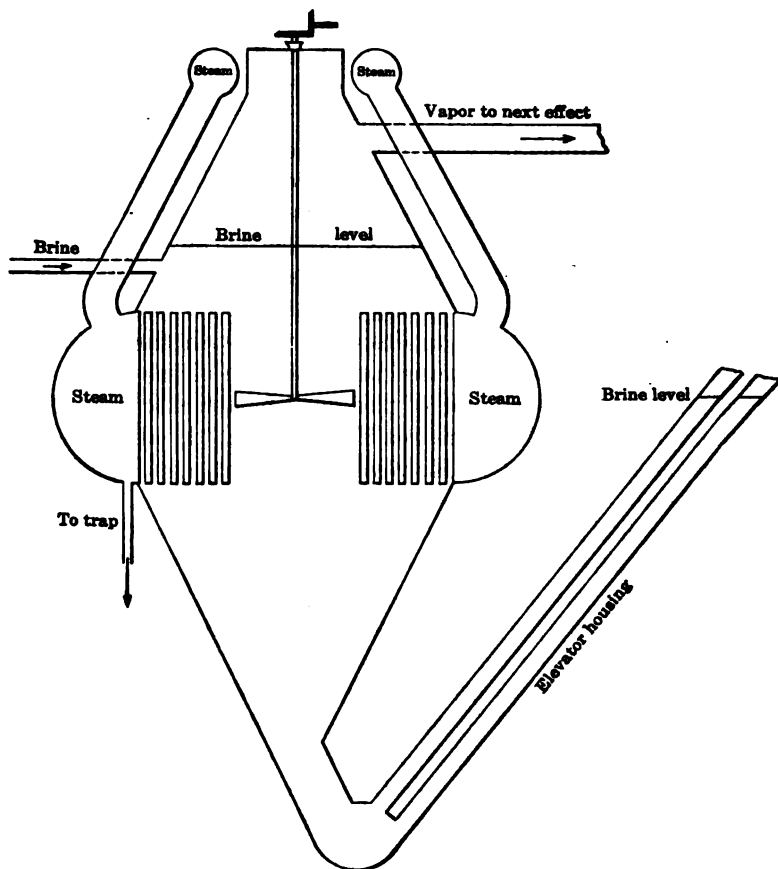


FIGURE 4.—Essential parts of vacuum pan.

CHARACTER OF PRODUCT.

The salt produced by the vacuum-pan process has a fine luster and a closely even grain, which adapts it for table and dairy use. The crystals have nearly perfect cubical shapes that distinguish vacuum-pan salt from that made by other processes. The fine grain is due chiefly to the rapidity with which the salt crystallizes, and the rapidity of crystallization depends on the degree of vacuum, amount of steam, the height of brine in the pan, and other factors.

PRINCIPLE OF VACUUM-PAN PROCESS.

The vacuum-pan process in which multiple-effect evaporators are used represents the latest development in salt making. The apparatus used in it is more complicated than that employed in any other phase of the industry. The underlying principle of the process is the lowering of the boiling point of a liquid that results from decreasing the pressure of the vapor above the liquid. If a vessel of water is placed under the jar of an air pump and the air is partly exhausted the water will boil at a lower temperature than under ordinary atmospheric pressure, and the lowering of the boiling point will be greater the more nearly a perfect vacuum is approached. In vacuum-pan practice nearly complete exhaustion of the chamber can not, of course, be maintained, but the partial vacuum that is practicable effects appreciable lowering of the boiling point of the brine and consequently a distinct saving in fuel. For example, when the steam, which is the means of heating the brine, is at a temperature somewhat higher than 212° F. and the brine under partial vacuum boils at about 150° , water will rapidly evaporate from the brine.

Inasmuch as the boiling point of a liquid varies with the pressure to which it is subjected it follows that adjusting the pressure will produce corresponding changes of the boiling point, whereby it may be placed at will anywhere between certain practical limits. The lowest point is usually fixed by the cost of procuring the vacuum and is about 125° F. The upper limit is fixed by the temperature of the steam used, which for exhaust steam is about 225° F.

Obviously, with a given amount of heat for boiling, better results may be accomplished in a vacuum than under atmospheric pressure, and the greater the vacuum the greater the accomplishment with a given number of heat units. If, then, the cost of maintaining the vacuum, including the cost of the plant and its operation, is less than the value of the heat gained, evaporation of water by the vacuum-pan process is more economical than by the open-pan process.

With the open-pan process the heated vapor, containing a considerable quantity of heat units, is entirely lost, whereas in the vacuum-pan process in multiple effect this heated vapor is used to the greatest effect. A point that should be firmly borne in mind is that with the multiple-effect vacuum-pan system, each vacuum pan acts not only as an evaporator, but also as a boiler producing heated vapor or steam for boiling in the next succeeding pan and as the condenser for the pan immediately preceding. To make this point clearer, let assumptions be made as follows: The operation starts with steam from a main boiler plant that has a temperature slightly in excess of 212° F. The steam is led through pipe of suitable diameter into the steam belt of the first vacuum pan and is there condensed. The heat is transmitted through the tubes and absorbed by the liquor to be

boiled, which is under a vacuum of 15 inches. The liquor in boiling gives off heated vapor or steam, which passes as such to the steam belt of the second or No. 2 vacuum pan. This steam or vapor, instead of being at a temperature of 212° F., is at the temperature involved in the 15-inch vacuum—that is, approximately 175° F. With the liquor in the second effect under a vacuum of, say, 24 inches, the steam or vapor passing into it is amply hot to cause violent ebullition to take place. The ebullition in the second effect in turn produces heated vapor or steam, which is led to the steam belt of the third pan, which is under a vacuum of 27 inches. The steam from the second effect, which is at a temperature of 140° F., is amply hot to produce boiling in the third pan at the desired rate. The steam from the pan in which the vacuum is 27 inches at a temperature of 110° F. is again in turn hot enough to produce boiling in the fourth effect, which may be assumed to carry a vacuum of $28\frac{1}{2}$ inches.

CONSTRUCTION OF APPARATUS.^a

The vacuum pans usually are vertical cylinders with conical ends and are commonly constructed of iron or steel, though a vacuum effect at one plant is built of copper heavily lined with tin. The detail drawings indicate their construction. The pans are installed singly, in pairs, in threes, and in fours, and with their mechanical attachments are referred to as "effects." Thus a single pan is a single effect, two pans in series a double effect, three pans a triple effect, and four pans a quadruple effect. Series of two or more pans in general are referred to as multiple effects. Pans less than 9 feet in diameter are not common and most are between 10 and 20 feet in diameter. With the constantly increasing demands for evaporators of large size, pans with diameters greater than 20 feet are becoming increasingly common, and a pan has recently been made with a diameter of 30 feet. (Pl. XV.)

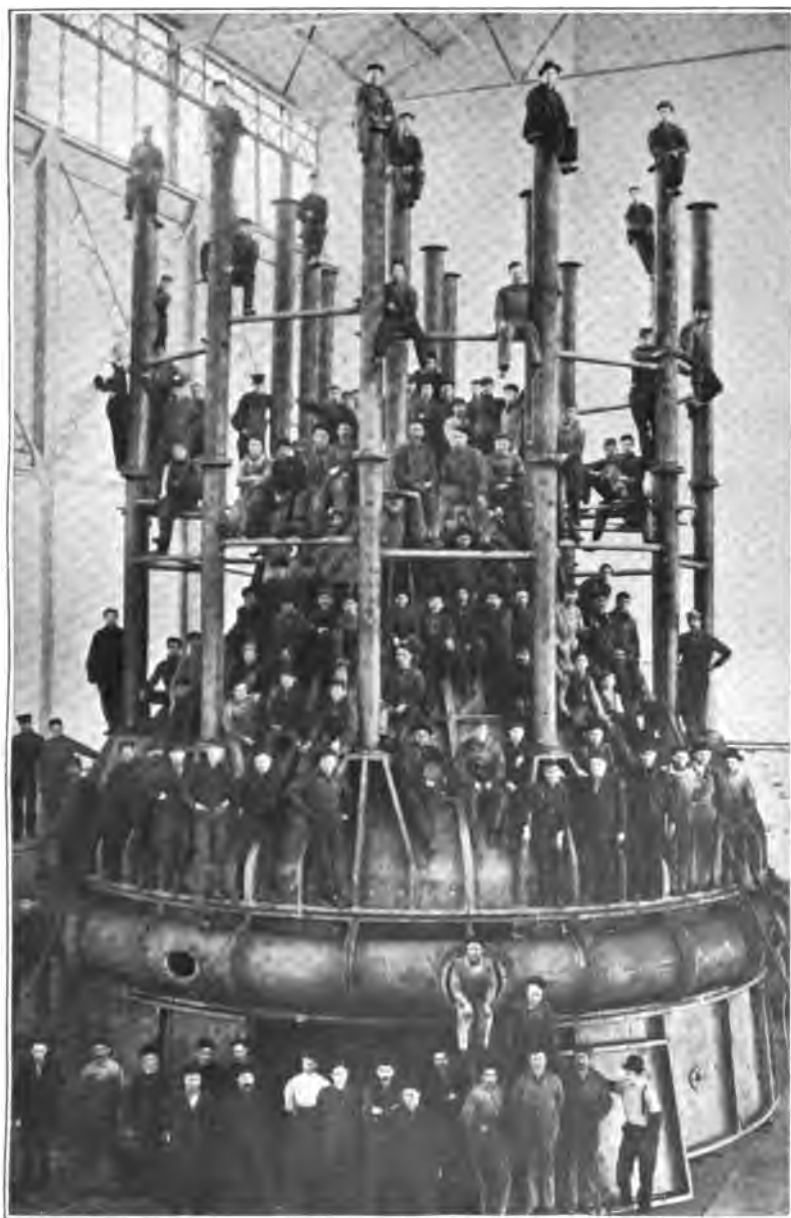
Pans 10 to 20 feet in diameter usually measure 30 to 50 feet from tip to tip of the end cones (see Pls. XVI and XVII and fig. 5), and therefore they have to be tended from different floors.

The steam belt is placed in the cylindrical part of the effect. It consists of a ring-shaped belt of several hundred vertical copper tubes about 5 feet long and 2 inches in diameter.

The warm brine from the preheating or settling tanks ^b enters the pan at different places in various makes of pan. At Silver Springs, N. Y., the brine enters near the 14-inch gate valve. (See fig. 5.) At Del Ray, Mich., the brine enters about 6 feet above the salt outlet, and the salt is thus washed with a solution of pure brine. At another

^a Specific points in construction are given in the descriptions of individual makes of pans in subsequent pages.

^b Cold brine goes to the vacuum pan at one plant in Ohio, but this is very unusual.



THIRTY-FOOT PAN (LARGEST IN THE WORLD AND CAPABLE OF PRODUCING IN TRIPLE EFFECT 1,000 TONS OF SALT A DAY). LOWER CONE, STEAM BELT, TAPER PLATES, AND COLUMNS, INVERTED ON ERECTING FLOOR. WORKMEN PUT ON TO SHOW PROPORTIONS. (COURTESY OF MANISTEE IRON WORKS, MANISTEE, MICH.)



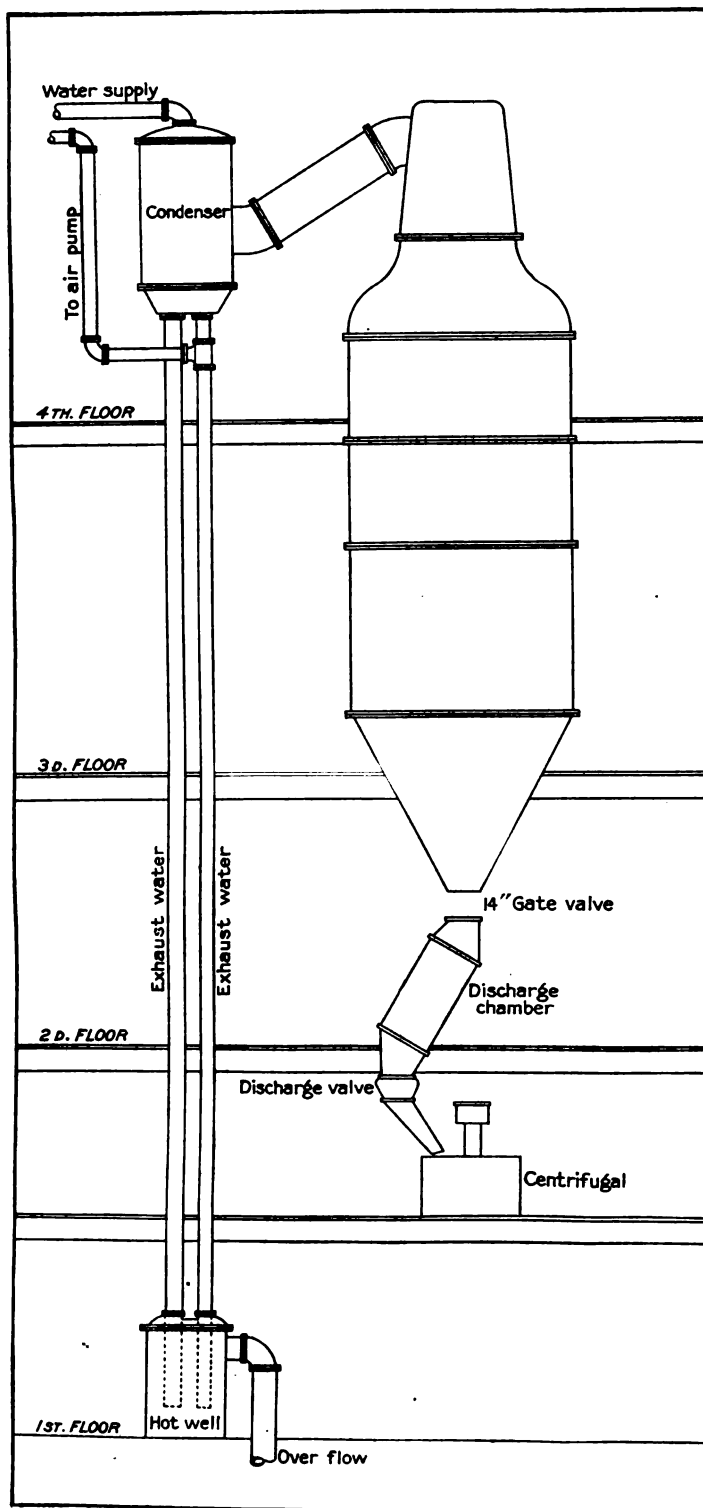


FIGURE 5.—Section of a single-effect vacuum pan, with gate valve, discharge chamber, and centrifugal at base. This type differs from those shown in Plates XVI and XVII in the method by which the salt is removed.

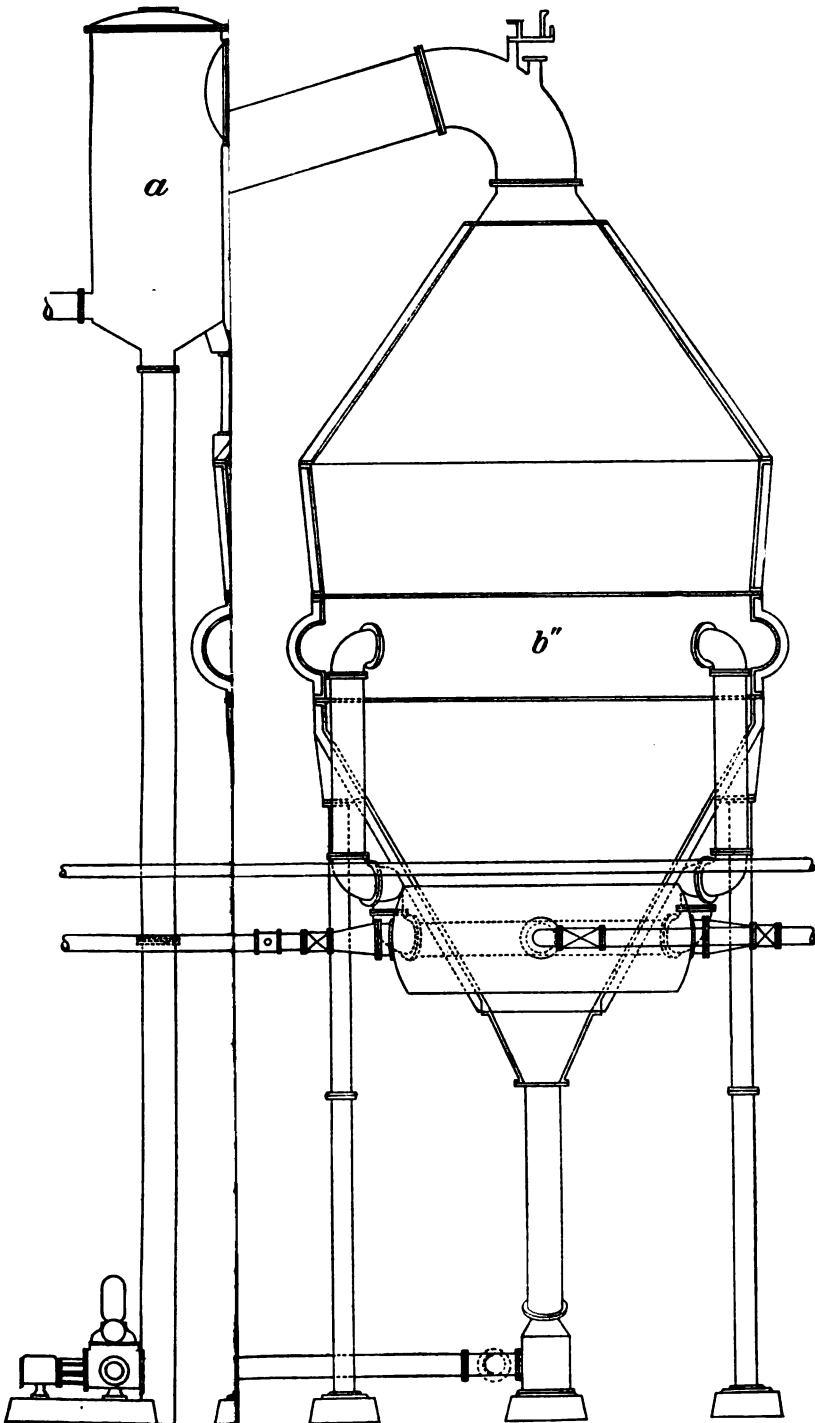
plant the brine enters near the base of the pan during the preliminary filling but above the steam belt after the operation is well under way. Introduction of the brine above the steam belt is the usual method. The brine is boiled at a low temperature, depending on the vacuum maintained, and as the salt forms it falls by gravity into the elevator boot and is carried by an endless-chain elevator to the draining bins, from which it is taken to the storage bins after it has drained a sufficient length of time.

DETAILS OF OPERATION.

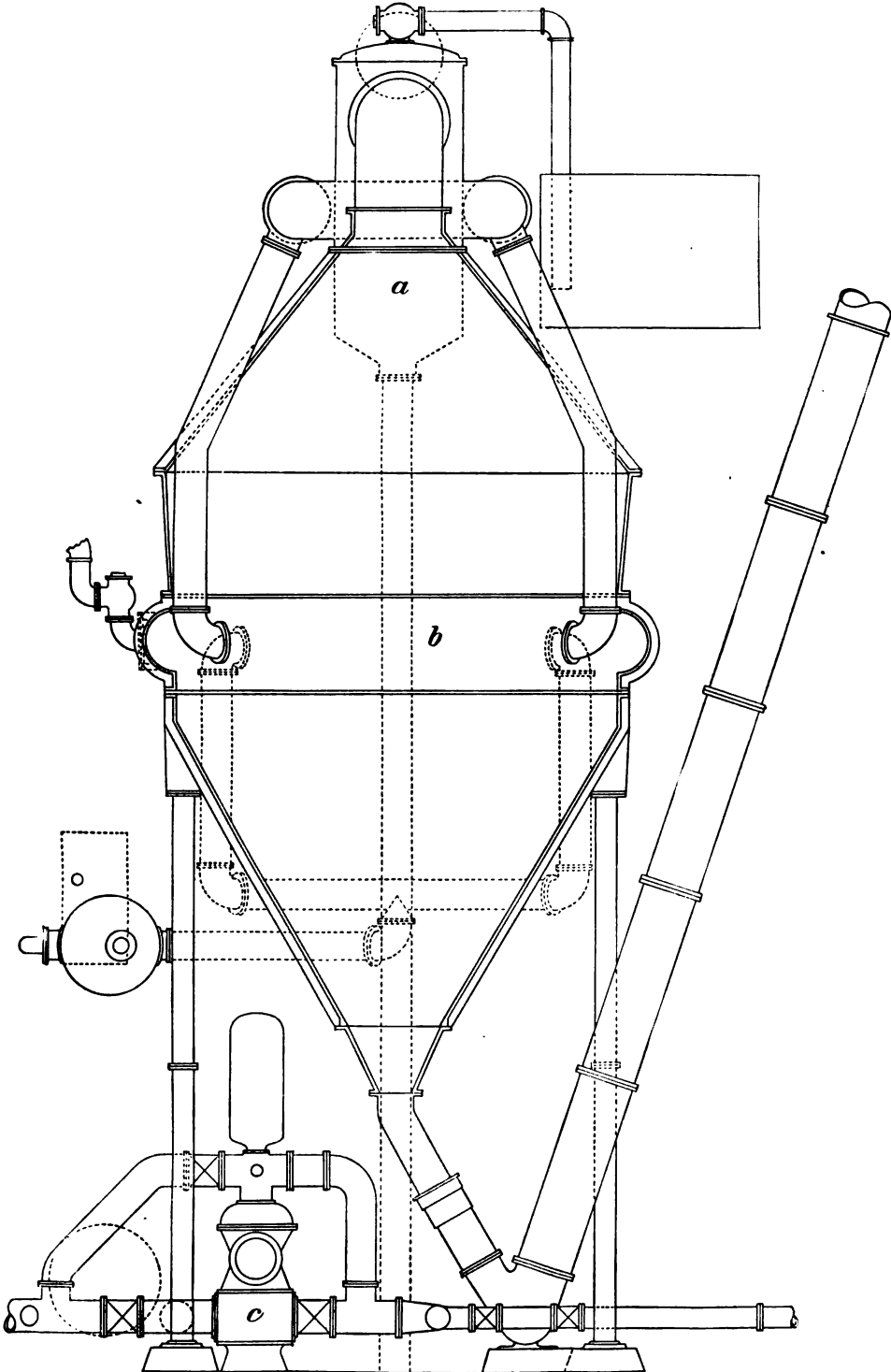
MANISTEE EVAPORATOR.

The details of operation differ with the make of pan and with the individual in charge. For general descriptive purposes the manipulation of the Manistee pan has been selected, as it is a type in common use. Other makes are described subsequently. The steam, either direct or exhaust, enters the steam belt usually but not always at rather low pressure. It is led to a ring surrounding the top of the effect, and thence through pipes to the steam belt below. The condensed water, which is trapped off from the steam belt of each effect, may be used in the manufacture of artificial ice, in boiling out the pans, or in the boilers of the plant, or it may be thrown away. It may be brackish in all but the first effect. As the brine boils, the steam rising from it in the body of the first effect passes through a gooseneck into the steam belt of the second effect, the steam from the body of the second effect passes likewise through a gooseneck into the steam belt of the third effect, and so on throughout the series. The body of the last effect is connected with a vacuum pump, and the vapor is condensed by a jet condenser, thus helping to maintain the vacuum. Theoretically, the vacuum produced by the pump at the beginning of the operation ought to be kept up by the condensation caused by the flowage; the working efficiency is, however, not perfect, and the vacuum pump is operated all the time. The condensing water is usually allowed to go to waste, but at some plants a use is found for it, such as dissolving the salt underground. Its temperature is low, 80° to 90° F., so that not much heat is lost, and it is usually brackish.

The vacuum in the body of a single effect, measured in inches of mercury, ranges from 25 to 28 inches. At one plant where triple effects are used the vacuums in the first, second, and third effects were 15, 24, and 27 inches, and at another 14, 18 to 20, and 28 inches, the water in the effects boiling at correspondingly low temperatures. The aim is to maintain in the last effect a vacuum as nearly perfect as practicable. As the degree of exhaustion decreases progressively from the last to the first effect the brine boils at the highest temperature in the first effect and at increasingly lower temperatures in the others.



MANISTEE, MICH.)



END ELEVATION OF TRIPLE-EFFECT VACUUM PAN. (COURTESY OF MANISTEE IRON WORKS CO
MANISTEE, MICH)

As the solution boils it is in constant circulation, which may be assisted by a revolving wheel, which creates a downward current and consequently a return upward current through the copper flues in the steam belt. Thus salt crystals formed in the brine as it passes through the flues are carried by the propeller and gravity downward toward the boot.

As there is a constant tendency for the copper flues to become clogged with salt the pans are boiled out frequently in order to keep the heating surface of the flues perfectly clean and at their maximum efficiency. The brine drawn from the pan before boiling out goes either back to the settlers or to another pan. As bittern is formed rapidly in the vacuum-pan process the brine becomes impure after a few admixtures with such residual liquors and has to be entirely discarded at intervals.

The boiling out is usually done with fresh water once or twice a day to twice a week, the frequency depending in general on the rate of operation. At less frequent intervals, depending on the amount of gypsum in the brine and the rate of operation, the pans are cooled and the gypsum scale is removed from the copper tubes in the steam belt, usually by boiler-tube cleaners operated by compressed air. Scaling and boiling out are essential to keeping the pans at their maximum efficiency. Calcium sulphate, gypsum, or plaster, as it is variously called, is one of the main difficulties with which the salt manufacturer has to contend, and it is carried in greater or less amount by the brines of nearly all the important salt fields. It causes interruption to the process and laborious cleaning out, and it not only entails great loss of heat because of its low conductivity but it also causes the overheating of any metal exposed to direct fire. After a pan has been boiled out it sometimes makes salt that is not completely soluble in water or is otherwise unsatisfactory. Therefore, the first few dumps of salt made after a pan has been boiled out are usually not first class. If a pan makes off-color salt or salt that gives a cloudy brine it may be necessary to boil out more frequently or perhaps to change brine.

The salt as it forms settles into the lower part of the effect and into the elevator boot. As the brine in an effect is under a partial vacuum the level of the brine in the elevator housing above the boot is lower than that in the pan. (See fig. 4.) The salt passes through the brine in the elevator housing in the endless bucket conveyor, which is usually inclined (see fig. 4), though at one Ohio plant it is vertical, claim being made that this arrangement saves wear and tear. The salt is conveyed in the elevator either to bins with false bottoms, in which it is allowed to drain, or to a centrifuge, by which the excess of moisture is removed. The dry salt is then conveyed to the storage bins. The drippings are usually returned to the pan.

Another modification of the vacuum pan, used at a few plants in the United States, is distinguished by the method of discharging salt from the bottom of the pan. (See fig. 5). The peculiar feature of this pan is the discharge valve, through which the operator can draw off the bittern with each dump of salt. When the pan is being operated, the discharge valve is closed and the gate valve is open. After the discharge chamber has been filled with salt the gate valve is closed and the discharge valve below is opened. In this manner the salt and the bittern are removed without loss of vacuum in the pan, the discharge chamber playing a rôle similar to that of an air lock in the pneumatic method of excavation. By this arrangement the salt may be dumped 4 or 5 times an hour or about 100 times a day. The mixture from the discharge chamber runs into a centrifuge, by which the moisture is reduced to the practical minimum, the mother liquor running to the sewer. The salt is then ready for the next stage in the process of preparation for market.

OTHER TYPES OF EVAPORATORS.

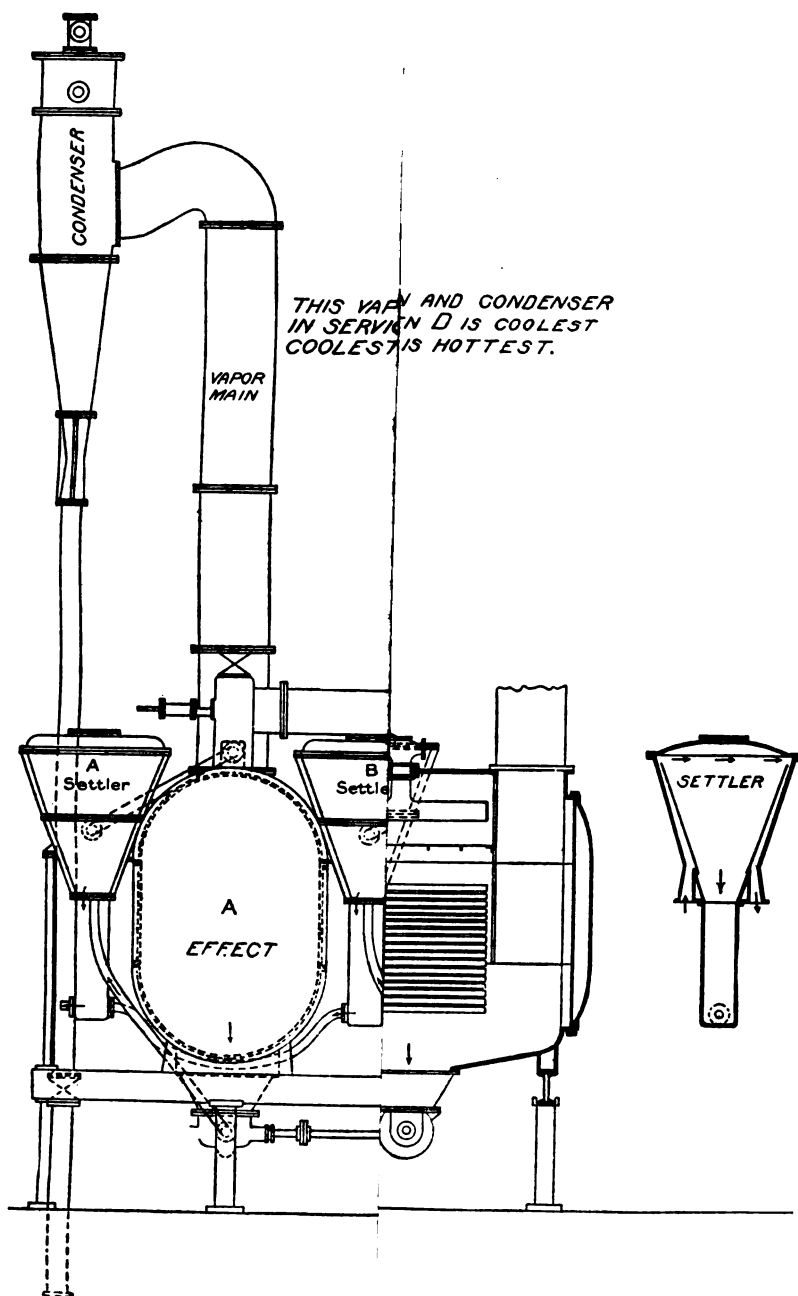
In 1916, the author visited many plants making single and multiple effect salt evaporators. If a personal visit was not practicable, information was requested by letter as to special types of evaporators. Brief descriptions of the different types follow. Some descriptions have been obtained from catalogs issued for public circulation, and others have been abstracted from a report by Cole.^a It is requested that manufacturers communicate with the writer if they make a salt evaporator of a type different from any described in this report. Information from manufacturers regarding corrections to the descriptions of their special makes will be gratefully received for future editions of this report, if such are issued.

LILLIE EVAPORATOR.

Certain manufacturers of salt use a type of Lillie quadruple-effect evaporator that differs in several respects from the above described type and which has been developed from the evaporator used in the evaporation of sirup from cane juices. (See Pl. XVIII.) Some of its distinctive points are film evaporation and mechanical circulation, the manner of distributing the circulating liquors over the horizontal unsubmerged evaporating tubes, and the reversal at will of the course of the vapors or the heat through the multiple effect.

The effects have the form of cast-iron horizontal drums set side by side with the steam end of one adjacent to the vapor end of the next, the copper tubes that provide the heating surfaces being set

^a Cole, L. H., *The salt deposits of Canada and the salt industry*: Canada Department of Mines, Mines Branch, 1915, pp. 124-125.



near one end of each effect.^a The steam is trapped from the steam end of the first effect to the steam end of the second and mixes there with the steam evaporated from the brine of the first effect. The steam in the third effect is supplied by steam trapped from the steam end of the second and the vapor from the second, and so on. The vapor end of the last effect is connected with a condenser and this in turn with a vacuum pump used to start the apparatus and to remove occluded air or gas from the brine. The brine and salt are moved by a centrifugal pump set in the middle of the apparatus on a horizontal shaft that extends throughout the entire length of the apparatus and carries connected with the hopper of each effect smaller centrifugal pumps that agitate the brine in its effect but do not move it forward. The salt carried with the brine exerts on the apparatus a scouring action which keeps it free from scale.

Another aid in keeping the apparatus clean is the periodical reversal of the flow of steam and brine, by which the first effect, which is under one set of conditions the hottest, becomes the coolest and the last effect becomes the hottest. The salt and brine ordinarily go from the first effect to the adjacent settler, from which the brine and some of the salt go to the second effect, but they may go immediately to the second effect and so on to the end of the apparatus. Thus the salt produced in all effects may circulate in the last effect and cause considerable scouring. Each effect draws sufficient brine from the brine line to keep the brine in the effect at the proper level.

Some descriptive details abstracted from a prospectus issued by the company making the apparatus follow:

The evaporating tubes incline slightly downward toward the steam end and open through the heavy tube-plate partition, in which they are firmly expanded without annealing and by which they are supported. The other ends of the tubes are closed, save for a small air vent in each, and are not fastened or supported, thus being free to expand or contract independently of the shell of the effect. The centrifugal circulating pump underneath and midway between the ends of the evaporator is sometimes omitted, in which case the liquor rises in the body sufficiently to float the feed-valve ball float that regulates the feed into the body. In a multiple effect the steam condensed inside the tubes flows into the steam end and thence through a steam trap into the steam end of the next cooler effect and finally into the atmosphere from the coolest effect. The solution circulates over the tubes in a deluging shower maintained by the centrifugal pump. The circulation is independent of ebullition.

The perforated distributing plate above the tubes is formed in sections for convenience in handling. Above each vertical row of

^a Young, C. M., Notes on the evaporated salt industry of Kansas: Eng. and Min. Jour., vol. 88, Sept. 18, 1909, pp. 558-561.

tubes it has one row of holes, three-eighths inch and greater in diameter. The heavy flow of solution down the surface of the tube plate through the inch space between the distributing plate and the tube plate prevents matter from caking on the tube plate, and the flow of solution through the inch spaces on either side of the tube plate prevents clogging of the perforated plate by particles of scale and other solids. This foreign matter is discharged from each effect with the liquor and is finally discharged from the last effect.

The circulation of both vapors and brine or of either alone may be reversed. Reversal of either permits taking the dilute solution into the coolest effect and delivering it concentrated from the hottest effect when desirable; that is, when a liquid is to be concentrated to a high density.

BRECHT SALTING EVAPORATOR.^a

The Brecht salting evaporator is manufactured by the Brecht Co., St. Louis, Mo. It can be operated in either single or multiple effect as required.

It consists, essentially, of three parts—the evaporator shell, the heating chamber, and the salt filter. (See Pl. XIX.)

EVAPORATOR SHELL.

The evaporator shell is generally made of steel and is cylindrical, with domed top and cone-shaped bottom. Suitable observation holes and a water gage are attached to the cylindrical body, and an air-tight manhole is placed near the top.

HEATING CHAMBER.

The heating chamber is one of the essential features of the Brecht evaporator. It consists of a steam drum in which a number of steel or copper tubes are placed vertically. These tubes allow the brine in the evaporating chamber to circulate freely to the cone-shaped bottom and to return again to the upper part of the evaporator. The drum is cylindrical and fits within the steel shell, where it is suspended on lugs attached to the side. The steam, from which the heat is obtained, enters the top of the drum, and, by a series of baffle plates so arranged that the direction of the steam travel is at right angle to the tubes, all the tubes are heated equally. The steam is thus constantly in circulation until it condenses and is drawn off by suitable means from the bottom of the drum. The tubes are made of either steel or copper, as required, and are 4 inches in diameter, the large bore obviating clogging as the salt crystals form.

^a Cole, L. H., *The salt deposits of Canada and the salt industry*: Canada Department of Mines, Mines Branch, 1915, pp. 124-125.



BRECHT EVAPORATOR.

SALT FILTER.

The salt filter is so constructed that the crystals of salt may be removed at any time without interfering with the process of evaporation. Connections are provided on the filter so that steam or air may be introduced into the salt for washing out the liquor and drying the salt. The salt filters are built of cast iron and the filtering medium is composed of perforated-brass sheets and fine brass-wire cloth. Plate XIX gives an idea of the appearance of a single-effect evaporator of this type.

CRANEY VACUUM PAN.^a

The Craney type of steam-vacuum pan (Pl. XX) for the manufacture of salt, with modifications or improvements, is now being made at the Bay City Iron Co., of Bay City, Mich. (The Manistee Iron Co., of Manistee, Mich., also make a type of the Craney pan.) It is constructed of steel plate with a conical top and bottom and a steam belt, just above the conical bottom, of such construction as to produce rapid circulation of the brine in the pan. To the lower cone is connected a cast-iron conduit, in which is operated an endless chain for the continuous discharge of the salt as it is formed. Connected with the upper cone is a cast-iron vapor pipe leading to a jet condenser. The apparatus is erected at a sufficient elevation, and the brine is carried in the pan sufficiently high to seal the vacuum in the open elevator. A pan of this type with a diameter of 8 feet is said to be sufficient to turn out about 400 barrels of salt per day when normal brine is used.

OSCAR KRENZ PAN.

A standard type of pan, known as the Oscar Krenz pan, has cast-iron steam belts and riveted tubes. The salt precipitates into a conically shaped bottom, and at certain intervals it drops into another receptacle holding about 500 pounds of salt. Thence it goes to a screw conveyor, which takes it to a centrifugal machine. The mother liquor is then run back to the supply tank. (See Pl. XXI.)

A quadruple effect is in use by one of the firms making salt on the Pacific coast.

SWENSON EVAPORATOR.^b

Construction.—The Swenson evaporator (fig. 6) consists of four essential parts—the evaporating chamber, the steam chest, the cone-shaped bottom, and the barometric leg. The evaporating chamber is dome shaped and of sufficient height to prevent loss by

^a Craney, Thomas, U. S. Patent No. 525757, dated Sept. 11, 1894, and No. 531912, dated Jan. 1, 1895.

^b Cole, L. H., The salt deposits of Canada and the salt industry: Canada Department of Mines, Mines Branch, 1915, pp. 120-122.

entrainment. The steam chest is fitted at the top and bottom with tube plates, into which are expanded a number of 2½-inch copper tubes. The downtake is in the center of the steam chest, and is of sufficient size to prevent the clogging of the salt crystals as they are formed. The brine circulates up through the copper tubes and down the central downtake. The salt crystals, as formed, drop into the

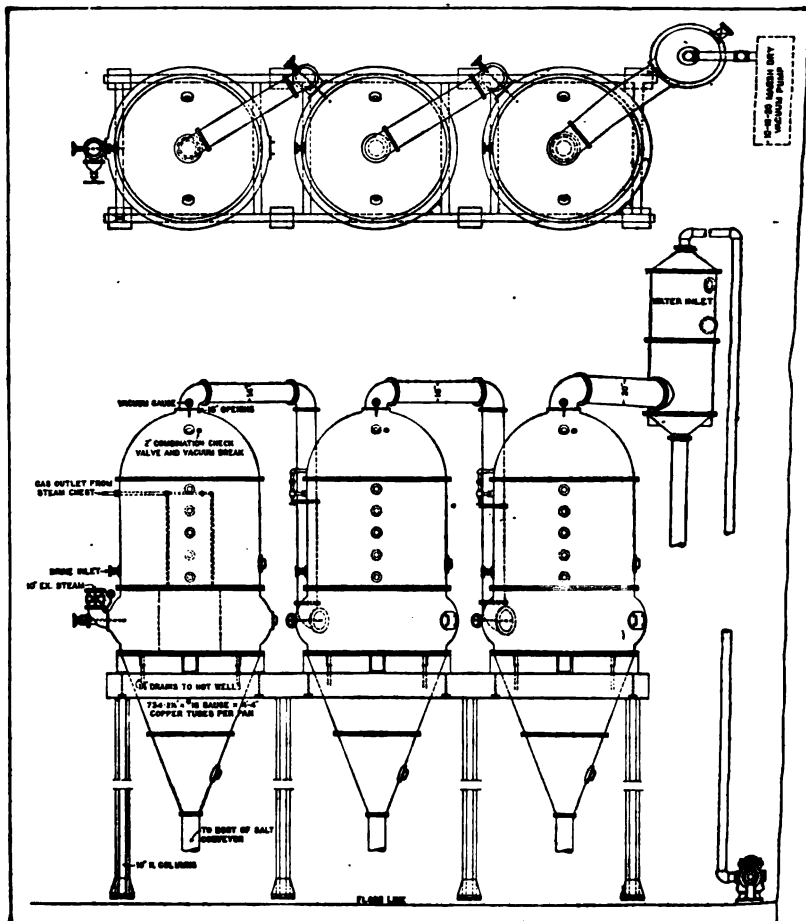


FIGURE 6.—Swenson triple-effect evaporator.

quieter part of the cone-shaped bottom, through the barometric leg into the boot of an inclosed elevator, which drops them into the drying bin.

OPERATION.

The operation of an evaporator of this type is continuous. Suitable means are provided for the removal of the inclosed gas in the steam chest as well as the condensed steam. The evaporators can be operated either in single or multiple effect.

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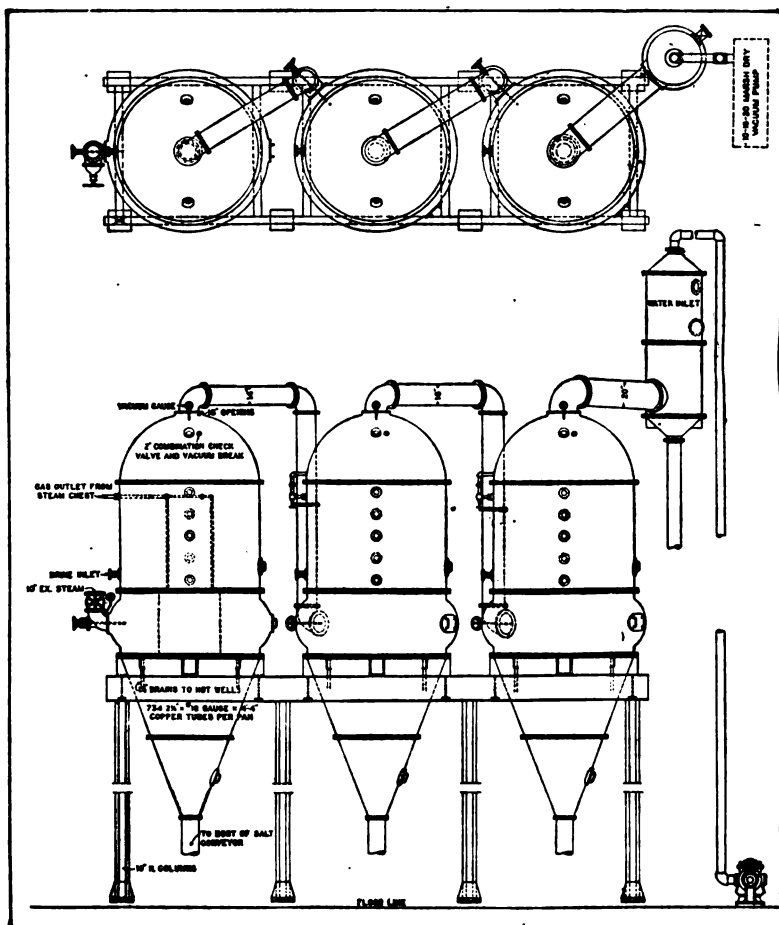
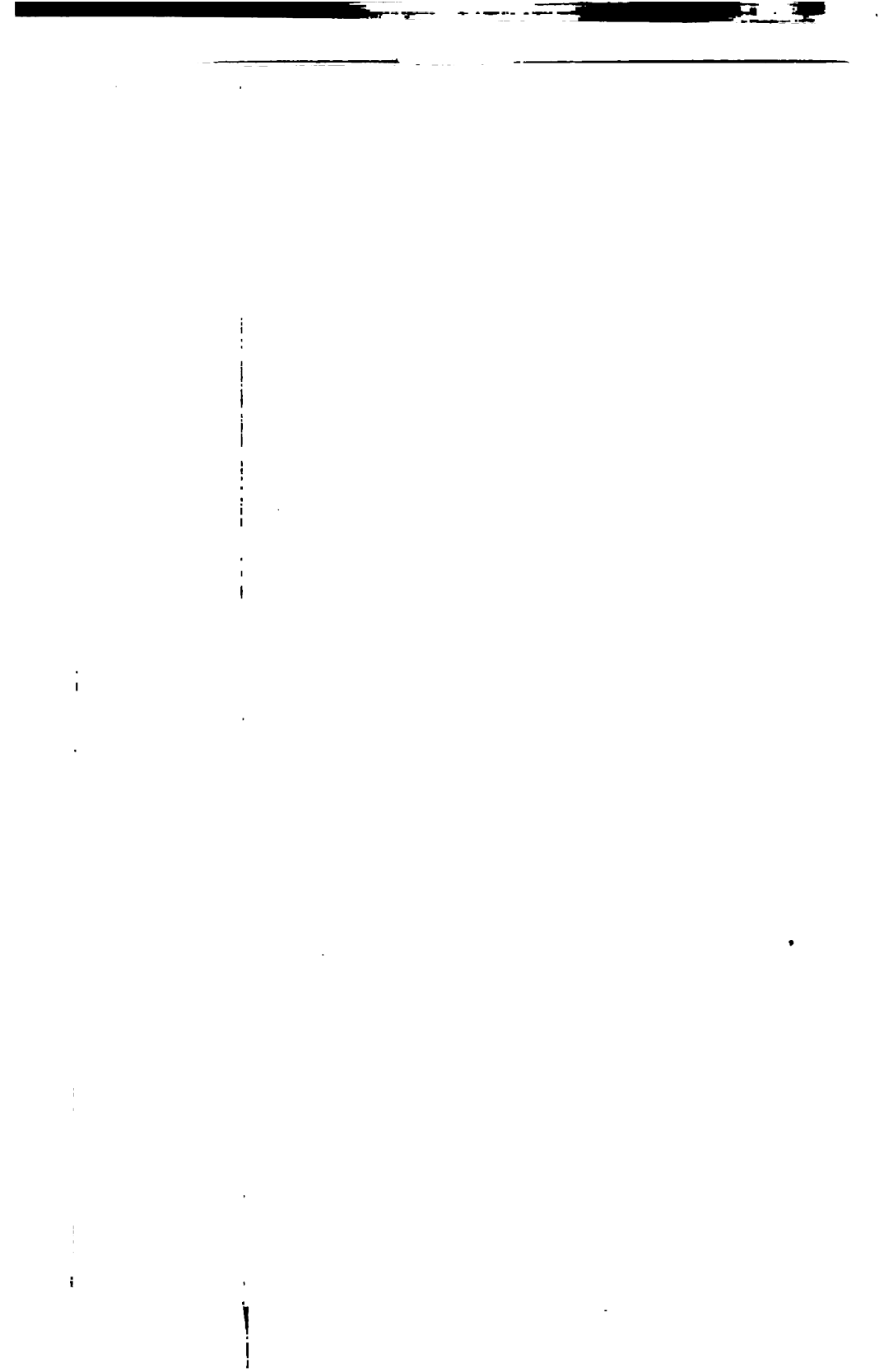


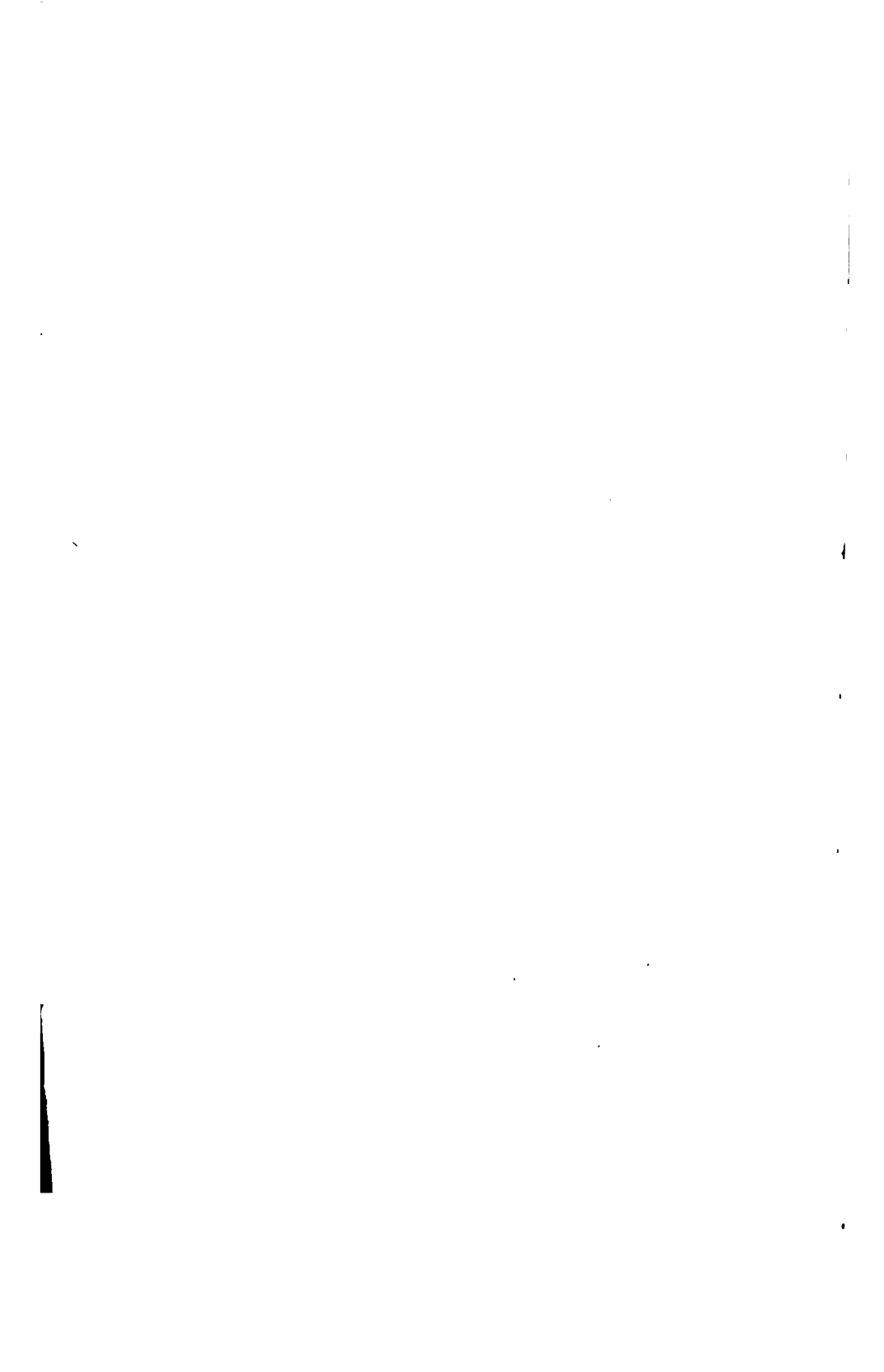
FIGURE 6.—Swenson triple-effect evaporator.

quieter part of the cone-shaped bottom, through the barometric leg into the boot of an inclosed elevator, which drops them into the drying bin.

OPERATION.

The operation of an evaporator of this type is continuous. Suitable means are provided for the removal of the inclosed gas in the steam chest as well as the condensed steam. The evaporators can be operated either in single or multiple effect.





SANBORN EVAPORATOR.

The following description of the Sanborn evaporator (fig. 7) is taken from Cole's report.^a

CONSTRUCTION.

The general construction of these evaporators consists of evaporating shell, heating element, cone-shaped bottom, and salt filter.

The essential difference in this make of evaporator is in the heating element. The steam by which the brine is heated circulates inside the tubes, with the brine outside the same, instead of the brine within the tubes. The heating surface is composed of tubes 2 inches in outside diameter, No. 16 Stubb's wire gage, of seamless drawn copper (or other metal, as required), having their lower or open end rigidly expanded to the full thickness ($2\frac{1}{2}$ inches) of the main tube sheet. The upper end of each tube is seamlessly closed, and projects entirely free into the brine compartment of the evaporating chamber. The tubes, as usually supplied, have 4 feet of exposed tube above the upper face of the main tube sheet.

The inner tubes, whose function is the continuous removal of all air and noncondensable gases immediately upon their separation, are of $\frac{1}{4}$ -inch brass tube, iron-pipe size, and extend to the extreme top of each heating tube. The lower extremity of each inner tube is connected to the secondary tube sheet by either a reverse brass bushing or a special shaping of the tube itself.

The assembly of these inner tubes in the apparatus is extremely simple; the tube being entered from below, with the tube sheet in position, until the bushing or expanded portion of the tube reaches the counterbored lower face of the secondary tube sheet, and is then screwed solid with a brace carrying a screw driver or socket-wrench attachment. All the inner tubes open into a shallow compartment beneath the secondary tube sheet, and the eliminated air and gases are immediately delivered into the steam chamber of the next effect. The condensation formed on the heating surface is released as soon as formed, falling from the mouth of each open, vertical, heating tube, onto the secondary tube sheet, from where it is withdrawn by suitable means.

The main tube consists of a cone-shaped cast-iron sheet, $2\frac{1}{2}$ inches thick, while the secondary tube sheet is of the same cone shape, but only $1\frac{1}{2}$ inches thick, and is also made of cast iron.

The salt filter is furnished with a quick-detachable strainer, which can be withdrawn in an instant, if necessary; although, in general operation, this strainer remains constantly in position.

OPERATION.

The steam is delivered into the steam chamber or calandria, which it completely and uniformly fills, and ascends, by the natural tendency of heat to rise, into the open end of each heating tube equally. The natural circulation of the steam in a vertical direction, inside of each tube, is materially facilitated by the immediate condensation in each tube, and further assisted by the upward current induced by the continuous withdrawal of the air and noncondensable gases from the highest points.

In this type of evaporator the brine is all outside of the heating tubes, and no down-take is used. The sharp-coned bottom permits the crystallized salt as formed—under the influence of its own weight and in the presence of the violent agitation of the boiling brine—to all drop to the lowest part of the cone, thence to fall directly into the salt filters, whence it is removed as needed.

^a Cole, L. H., Report on the salt deposits of Canada and the salt industry: Canada Department of Mines, Mines Branch, 1915, pp. 127-129.

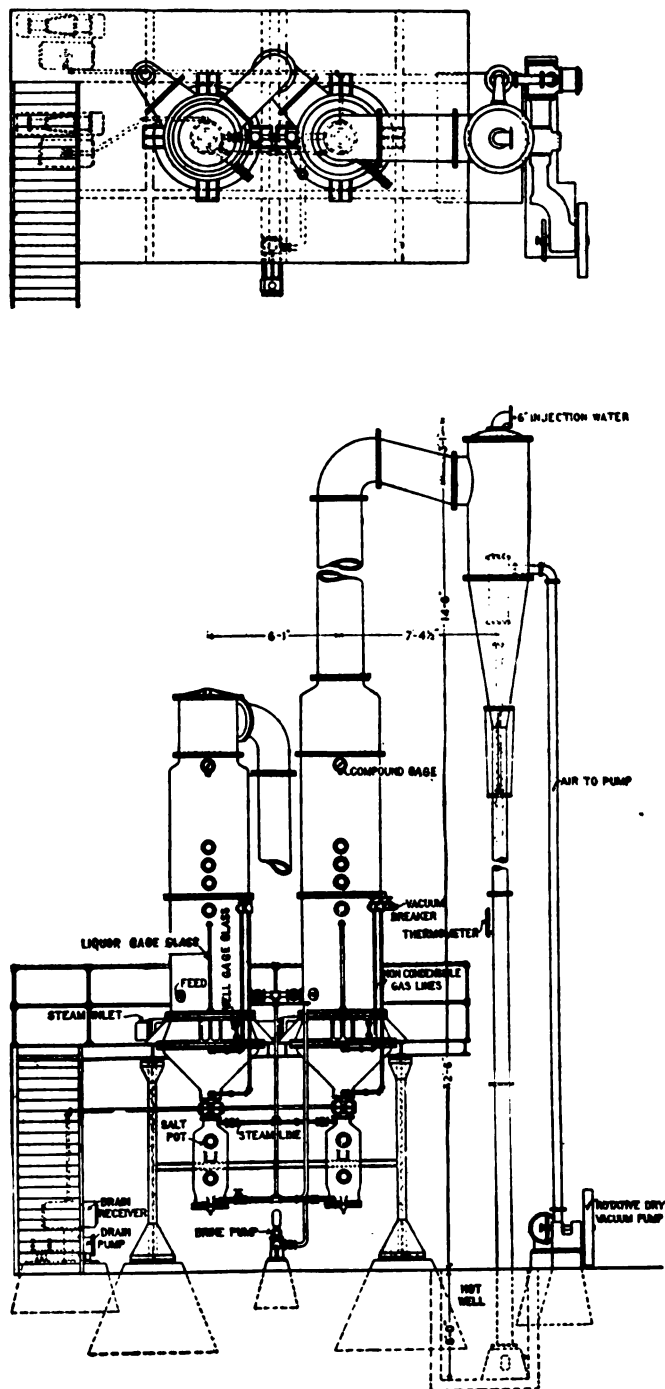


FIGURE 7.—Sanborn salt evaporator.

WHEELER EVAPORATORS.

Wheeler evaporators (fig. 8) and multiple effects with standard, vertical-tube calandrias are best known in the sugar industry, where many are in service.

The pan of each vessel is usually of cast iron with a dish-shaped bottom, above which is the steam-belt course, and above this, the courses forming the vapor space and dome. Above the dome is a catch-all, which returns the unevaporated liquid entrained in the vapor to the boiling space. The steam belt contains the calandria, which consists of vertical tubes 2 to 3 inches in diameter, secured into horizontal circular tube plates. Steam circulates on the outside of the tubes, and the liquid to be concentrated boils within the tubes. The circulation of the liquid is upward through the tubes and downward through the downtakes.

In the evaporation of salt solutions particular attention is given to the removal of crystals. These are thrown down from concentrated solutions and must be removed continuously. Removal is accomplished by duplicate filter boxes, or by a long settling leg provided with a strainer and a continuous carrier.

The vertical tubes of a calandria are cleaned periodically, the intervals between cleanings depending on the service. Often, as in sugar houses, the tubes are treated with diluted solutions of acids, which soften and loosen the scale. A wire brush, rotated by an external-air motor, is then run through the tubes, or a turbine cleaner is used, similar to that used for cleaning water-tube boilers. For steel calandria tubes a cutter head is used, and for copper tubes a thin wire brush head.

Vacuum or strike pans are built with horizontal copper coils, as well as with tubes as described.

ZAREMBA CRYSTALLIZING EVAPORATOR.^a

CONSTRUCTION.

The Zaremba crystallizing evaporator consists of two parts: (1) The evaporator body, in which the evaporation occurs, and (2) the salt filter underneath, by means of which the precipitated crystals are separated from the concentrated liquor, washed clean, and removed from the system.

HEATING SURFACE.

The shell of the evaporator body is built of heavy cast iron or steel. Its lower part, below the heating surface, consists of a cone into which the salt is precipitated and funneled into the salt filter below.

^a Data furnished through the courtesy of Edward Zaremba of the Zaremba Co.

Mounted within the shell immediately above the cone is the cylindrical steam chest, fitted at top and bottom with disked heads of steel into which 2-inch charcoal-iron tubes are expanded. The fastening of the steam chest in the shell is effected by means of a special design. The tubes are slightly inclined from the vertical to facilitate circulation and prevent possible loss of liquor. Copper tubes may be used for corrosive liquids.

CIRCULATION.

The downtake is an annular opening, widest at the bottom, extending entirely around the steam chest. Circulation of liquor is upward through the tubes, outward toward the top of the downtake, downward between the steam chest and the exterior shell, and then inward to the lower end of the tubes. This action produces a ready separation of the salt crystals from the boiling liquor, throwing them into a zone of quiet in the conical bottom and thence into the salt filter.

SALT FILTER.

The filter consists of a cylindrical chamber fitted with a filter screen placed close to the bottom. At the front and immediately above the screen is a swinging door through which the separated salt is removed. The conditions inside can be observed through the sight glass. Wash water is introduced through perforated pipes mounted under the top cover of the filter. Vacuum and liquor pumps connected to the system are adequate to provide for all requirements.

METHOD OF OPERATION.

Evaporator.—The brine or weak liquor enters the first effect at the top of the cone and flows to the base of the steam chest. By the action of the vapor generated in the tubes and the pressure exerted by the liquor in the downtake, a vigorous movement is set up within the tubes (about 30 feet per second), inducing rapid heat transmission and effective scouring action on the tube interiors. Owing to the large area of the downtake the return flow to the bottom of the steam chest is slow (about 3 feet per second or less), allowing the crystals formed during the concentration to separate from the liquor and drop gently into the zone of unagitated liquor contained in the cone. The heavy liquor carrying these suspended crystals flows out through the plug cock at the tip of the cone and into the salt filter.

Filter.—A liquor line connects the bottom outlet of the filter to the liquor inlet of the second effect, which, being under a higher vacuum, draws the liquor through the filter and into itself by suction. The suspended crystals are left behind on the filter screen, where they are allowed to accumulate until the salt filter is filled, as indicated by a sight glass. The connection between the evaporator

and the filter is now shut off by closing the plug cock between, and after the heavy liquor has been drawn off the contents of the filter are washed with weak liquor, hot water, and steam. The connection to the second effect is then closed, the discharge door of the filter is opened, and the thoroughly washed crystals are removed in an approximately dry condition.

After the filter has been emptied its door is closed and the contained air is removed by replacing it with steam. The condensation of the steam soon produces sufficient vacuum to pull the mixture of liquor and salt collected in the cone down into the filter, when the plug cock is opened. The liquor level in the evaporator is again brought to standard height and the filter is placed in circuit by opening the connection to the next effect. Where the quantity of salt precipitated is comparatively large two filters are attached to one evaporator body, thus making it possible always to have one filter connected to the evaporator, inasmuch as the filters are used alternately. By either arrangement the salts are washed and removed without interfering with the work of the evaporator above. If desired, the crystals can be dissolved within the filters and the saturated solution removed by pumping.

The method of operation in the second effect is the same as has been described, except that the heavy liquor is drawn from the filter by the suction of a pump. The liquor discharged from this pump is returned to the second effect to be recirculated.

These evaporators are built either as single, double, triple, or quadruple effects, and are generally connected in such a manner that any one of the bodies can be cut out of service without interfering with the others. Owing to the fact that each body of a multiple effect operates at a different temperature, by proper manipulation it is frequently possible to make a separation of salts where several compounds are present in the solution. Ordinarily, the weak liquor is fed to the hottest body and is finished in the coolest body, but for some purposes the flow of the liquor is reversed, thus giving what is known as the "countercurrent" system of working.

By installing a preheater for feed liquor a substantial reduction in the amount of steam used is possible. The evaporators are equipped with internal separators, which makes impossible the carrying over of liquor by entrainment as a result of careless operation.

The steam pressure used varies all the way from atmospheric to 60 pounds or more, depending on the circumstances. Ordinarily, direct-acting pumps are furnished, their exhaust being delivered to the evaporator. The condenser often can be so placed as to draw its own water by suction.

MILLING OPERATIONS.

The milling operations outlined below are generally involved only in the preparation of the grades of salt used on the table and in the dairy. The character of the grains of such salt is shown in Plate XXII. The salt is allowed to remain in the storage bins until it is thoroughly cured. The longer it remains in storage the less heat is required in subsequent drying. The centrifugals now used at many plants for the purpose of removing the brine and bittern from the salt crystals before storage are highly efficient and practically obviate the necessity of subsequent drainage and storage. Where a coarser grade than vacuum-pan salt is used for making table or dairy salt it may have to undergo a preliminary crushing.

After the removal of as much moisture as possible in the centrifugals or bins the salt is removed to the drier. This is a rotary cylinder which revolves slowly and is provided with steam pipes or a steam jacket or other equipment that heats the salt to a high temperature during its slow passage through the machine. At the front end of some driers there is an auxiliary steam coil and a blower to force in hot air and at the same time to blow out the lighter impurities, principally gypsum and moisture. Great care is exercised to prevent the dust from becoming disseminated in the plant; it is collected in an air-tight room and barreled. A fan at the rear end of the drier assists in the elimination of the gypsum, dust, and moisture. The salt after it has passed through the drier may contain as little as 0.1 per cent moisture.

The salt from the drier (Pl. XXIII, A) is passed through screens (Pl. XXIII, B) to remove lumps and to assort the grains for the trade. Cylindrical wire-mesh screens, shaking screens, or bolters are used. The grains of various size are deflected into hoppers and thence to bins. At some mills the salt is run from the bins to automatic weighing machines and into the cartons in which it appears in the trade. To render certain grades of table salt moisture proof and to make them run as freely as possible, a small amount—usually not more than 1 per cent—of some nonhygroscopic substance like magnesium carbonate is used to coat the grains.

The effort throughout the entire process in up-to-date establishments appears to be to take advantage of labor-saving devices. The salt is moved by hand as little as possible, screw conveyors, elevators, and other mechanical devices being adopted wherever practicable. The details of final manipulation are so varied at different establishments in the United States that only the general practice has been outlined.

COMBINATION SALT.

Most salt produced by the grainer process has a loose, light, flaky texture, though its character may be varied by varying the temperature and hence the rate of evaporation at which it is produced. If sufficiently high steam pressure is maintained, a rapid ebullition follows and the salt is granular. If the temperature is low, evaporation takes place chiefly from the surface of the brine and the salt is flaky or flocculent. In other words, the slower the rate of crystallization the larger the grain of salt. As grainer salt has certain characteristics for which there is considerable demand, and as it must be made slowly in order to produce a coarse grain, it commands a comparatively high price. The salt produced in the vacuum pan is a fine-grained or granular salt. "Combination salt," as the name suggests, is a product formed by combining the salt made by the two processes.

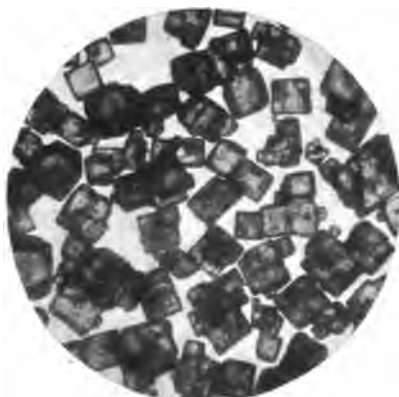
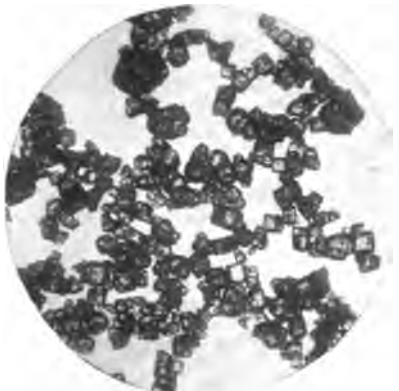
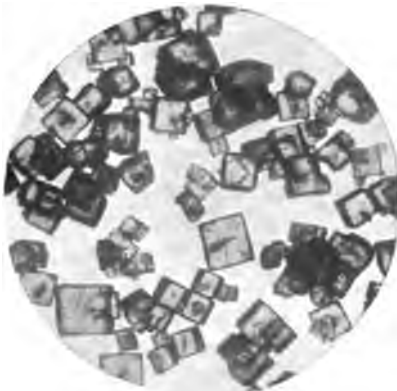
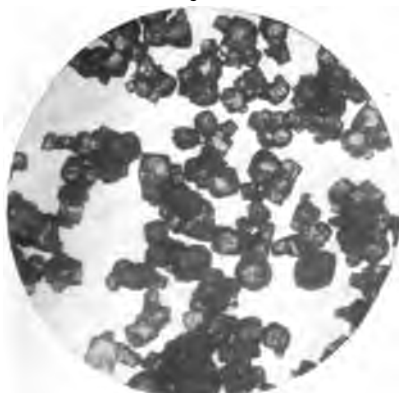
According to the process of making combination salt devised by Lillie^a the brine is evaporated in the vacuum pan in the usual manner, and the salt crystals formed fall to the lower part of the conical chamber below the steam tubes. The salt is then carried with brine under pressure through a pipe to the grainers in operation making grainer salt. The vacuum-pan salt, having been introduced into the grainer, falls to the bottom at the rear end of the grainer and is moved forward by the usual mechanical devices. The salt produced by evaporation in the grainer also settles to the bottom, where it comes in contact with the vacuum-pan salt. While the fine salt from the vacuum pan moves forward in the grainer it is subject to the action of the hot brine and to contact with the salt made in the grainer, and a combination grain that differs in character from that of both vacuum-pan and grainer salt is produced. The particles of solid salt probably afford centers of crystallization in the saturated brine.

The product is not simply a mixture of crystals of various texture but is uniform and peculiar in texture. The identity of the fine salt from the vacuum pans usually is quite lost and the product approaches in its physical character the salt made by the open-pan or the grainer process. The character of the combination salt may be altered by varying the proportions of vacuum-pan and of grainer salt, and many different grades of salt may also be made by varying conditions in the grainers.

COMMERCIAL STATUS OF PROCESSES.

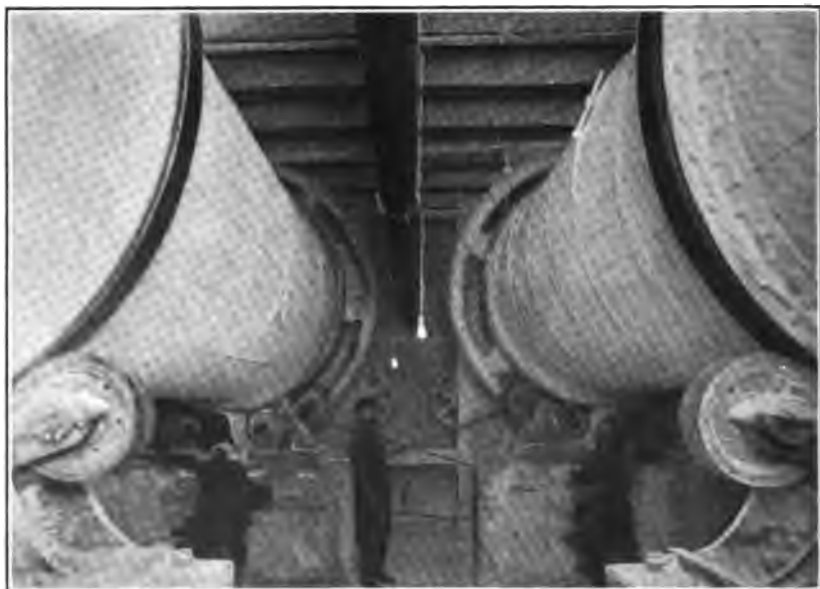
The wear and tear incident to the operation of all salt-making machinery is heavy. Moreover, if a salt block is allowed to lie idle for a year it becomes almost ruined; consequently, it is often cheaper to make salt for a season without any profit than to shut down.

^a Lillie, S. M., U. S. Patent No. 989002, dated Mar. 28, 1911.

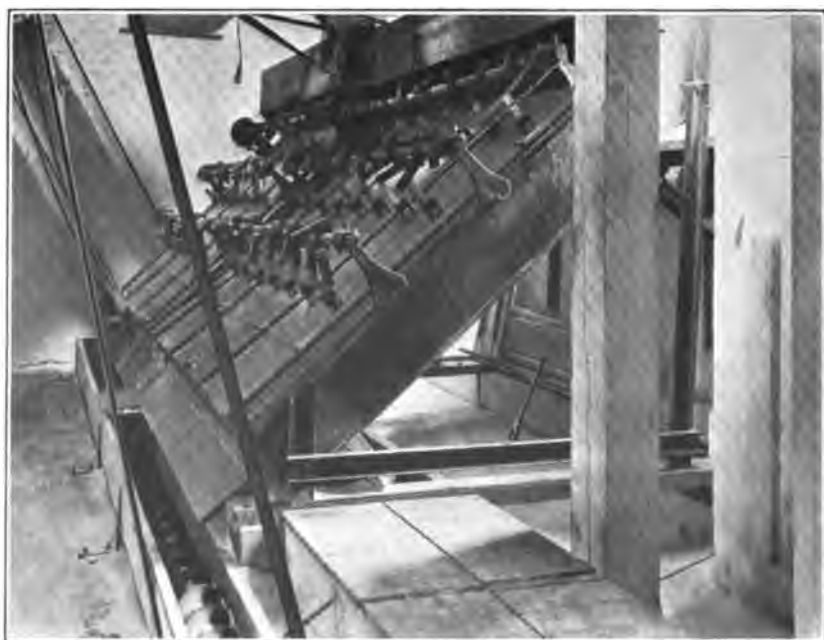
*A**B**C**D**E**F*

MARKET SIZES OF SALT. MAGNIFIED 18 DIAMETERS.

A, Salt made in a triple-effect Manistee vacuum pan by the Hutchinson Salt Co., Hutchinson, Kans.; *B*, Salt made by the Alberger grainer process, Diamond Crystal Salt Co., St. Clair, Mich.; *C*, Salt made in the Lillie quadruple-effect evaporator, San Francisco Salt Refinery Co., San Francisco, Cal.; *D*, Salt made in a single-effect vacuum pan, Worcester Salt Co., Silver Springs, N. Y.; *E*, Salt made in Lillie evaporating apparatus, Carey Salt Co., Hutchinson, Kans.; *F*, Salt made in a quadruple-effect vacuum pan, California Salt Co., San Francisco, Cal.



1. ROTARY CYLINDER DRIER USED IN DRYING HIGH-GRADE SALT.



2. TYPE OF SCREEN USED AT MANY SALT PLANTS IN UNITED STATES. NOTE SCREW CONVEYOR AT BASE FOR REMOVING THE SALT.

Apropos of this rapid deterioration, the following quotation from a letter of a practical salt maker of northern Ohio to the writer is worthy of careful consideration:

Another difficulty in fixing the exact costs is this: That in figuring costs and basing selling prices thereon, some salt producers do not provide for very rapid deterioration of salt-making apparatus, and it is unfortunate on that account and also on account of overproduction that many hundreds of thousands of dollars have been lost by salt producers in recent years.

The factor of overproduction is one for deep consideration by the manufacturers of salt in the United States. During the work of the writer in the different salt fields of the country, especially in the Eastern States, during 1911 and 1912, the consensus of opinion seemed to be that a great deal more salt was being produced than could be marketed, estimates of the overproduction ranging from 20 to as high as 50 per cent. The facts that large up-to-date plants at many places were not working at full capacity and that some were working only half time or at half capacity, while others were temporarily closed awaiting a better market or closed with no apparent prospect of reopening, present a significant situation to those planning to enter the business. According to one operator, "if the demand were doubled at present (Sept. 15, 1911) there would be ample apparatus in the United States to care for it and for a large surplus on hand." This operator spoke presumably of the eastern half of the United States, and the plant that he was connected with was working at only half its capacity. A similar situation must have existed some 30 years ago, for in 1888 Chatard^a said: "The present plants are able to furnish a supply much larger than can find a fairly profitable market." He began his report on salt-making processes in the United States, with the following statement:

The various elements which go to make up the cost of an article of commerce are found exemplified in the simplest and clearest manner in the salt industry. The raw material, the brine, has no other value than that given it by the cost of sinking the well and pumping; the fuel used is, so far as practicable, unsalable refuse; the machinery is of the simplest character, there being but little opportunity for the use of labor-saving devices; manual labor, mostly of a comparatively unskilled character, is almost exclusively employed; and the handling, transportation, and distribution of the product are effected in the cheapest manner, the foreign article being to a large extent brought in as ballast and sold at rates but little above those at the port of shipment.

Great changes have been wrought in the salt-making industry in 25 years and it is interesting to contrast the present (1915) situation with that existing when Chatard's paper was written. It is doubtless still true that the brine, the raw material from which all the evaporated salt is obtained, has no other value than that given it by

^a Chatard, T. M., Salt-making processes in the United States: U. S. Geol. Survey Seventh Ann. Rept., 1888, p. 497.



17. THE PUMP AND THE PUMP MOTOR.



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^a Chatard, T. M., Salt-making processes in the United States: U. S. Geol. Survey Seventh Ann. Rept., 1888, p. 497.

the cost of sinking the well and pumping the brine. But brine salt constitutes only 78 per cent of the total salt produced, as will be observed from the following table, and the cost of the preliminary work connected with mining the remaining 22 per cent is considerable.

Production and value of rock and brine salt in the United States in 1915.

Material.	Short tons	Value.
Rock salt.....	1, 165, 387	\$2, 299, 894
Brine salt.....	4, 187, 023	9, 447, 792
Total.....	5, 352, 410	11, 747, 686

In contrast with Chatard's statement regarding the use of unsalable refuse fuel, are the following comments by Willcox:^a

There is now going on in the salt industry, especially in Michigan, a transformation almost as radical as occurred when Michigan lumber first brought out Michigan salt. It is a change from the sawmill system of producing salt, in which fuel economy was no object, to a time that is almost here when fuel will be the main consideration. To illustrate what such a change means, refer to the early days when the Onondaga salt district in New York was the leading producer in the country. When the enormous Michigan production began to affect the eastern salt districts it hit the Onondaga district very hard, as can be inferred from the report published in 1877 of the superintendent of the Onondaga Salt Springs:

The business of manufacturing salt for the past season has been one of great embarrassment, owing to the general depression of business throughout the country and the consequent low prices afforded for the manufactured article; a result always incident to any market where the supply is largely in excess of the demand.

Another and, perhaps, more serious embarrassment grew out of the fact that a very large supply of salt has been furnished at the Saginaw saline. These works are, and must continue for many years to be, a vigorous competitor with our own.

So long as Saginaw continues the great center of a gigantic lumber trade, so long will she be a standing competitor in the production of salt. The refuse of her sawmills is estimated to be sufficient for the annual manufacture of 12,000,000 bushels of salt. During the past year her product has swollen to the enormous sum of 8,000,000 bushels. This refuse would be totally valueless for any other use than as fuel for the manufacture of salt. In fact, it would be a nuisance to the lumber dealers, because it would subject them to the expense of carting it from their works and destroying it.

This furnishes to Saginaw, without charge, what is to us the main factor in the cost of our product.

Thus it is evident that the old conditions have undergone great changes, and the time is in sight if not actually here when the salt industry, which has been a side issue, connected with the lumber business in certain parts of the Lower Peninsula of Michigan, must either stand on its own feet or pass altogether. Changing conditions already have brought about certain readjustments which must go forward to keep pace with the changing conditions in the lumber business if the salt industry, depending on the refuse from lumber mills, is to survive.

In the character of the machinery, the quality of labor, and the use of labor-saving devices there have been profound changes since the date of Chatard's commentary. The remarkable development of mechanically raked grainers and the establishment of the vacuum-pan process are indications of the advancement along such lines. In some of the modern grainer and vacuum-pan plants the salt is not touched by the human hand from the time it crystallizes from the brine until it is ready to be wheeled on board the cars. The character of the labor naturally, instead of remaining purely manual, has un-

^a Willcox, G. B., *Evaporation tests of a salt grainer*: Michigan Eng. Soc. for 1907, 1907, pp. 164-180.

dergone a complete change as more complex machinery has been adopted, until a large proportion of the work in the modern plants requires mechanical skill of an advanced type and the chemical engineer is called frequently into conference. All these improvements have tended toward increased efficiency and the production of a high-grade article at as low price as is compatible with the existing demand for high quality.

REMOVAL OF GYPSUM FROM BRINES.

One of the gravest difficulties encountered in salt making is the removal of gypsum. In practice the terms gypsum and plaster are both employed to designate the scale formed during the concentration of brines. The writer is not aware that the exact composition of the scale is known; it may correspond to the hemihydrate, $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$. Chatard suggests several methods for its separation, but at most plants the old method of stopping the process and scaling the gypsum is still employed. One of the reasons for this adherence to laborious cleaning is that any chemical treatment that effectually rids the brine of calcium sulphate, lime, magnesia, and oxide of iron is generally too expensive to be practicable, and, consequently, if used at all must be confined to the high-grade table and dairy products. Lime is almost universally used to remove iron, though sodium carbonate (soda ash) is used in some localities.^a

In the Alberger process the principle of superheating the brine at high pressure and releasing the pressure, thus effecting precipitation of the gypsum, is practiced. This is in line with a suggestion by Chatard^b that "in default of a chemical precipitant we are compelled to consider the application of heating alone as giving any reasonable prospects of improvement." He also called attention to the rapid separation of calcium sulphate near the point of saturation and at temperatures above 212° F. and suggested that the deposition of the sulphate and the recrystallization of the salt should, if practicable, be separate processes and that the apparatus to be used for the former process should be specially constructed to facilitate scaling. It is not yet established whether the separation of gypsum in this way is more efficient or cheaper than its removal by ordinary precipitation on the bottom of the open pan on the grainer pipes or in the flues of the vacuum pan, with the consequent labor and loss of time incident to scaling. The Alberger process is in limited use as compared with the other methods of making fine-grained No. 1 salt.^c

^a See patents issued to Charles Glaser and G. J. Muller on processes of refining salt: U. S. Patents Nos. 957416 (reissued as 13268), and 957417.

^b Chatard, T. M., Salt-making processes in the United States, U. S. Geol. Survey Seventh Ann. Rept., 1888, p. 502.

^c Persons interested in this problem will find many data and references to domestic and foreign literature in Chatard, T. M., Salt-making processes in the United States: U. S. Geol. Survey Seventh Ann. Rept., 1888, pp. 497-527; also in Cameron, F. K., and Bell, J. M., Calcium sulphate in aqueous solutions, Bull. 33, Bureau of Soils, 1906, 71 pp.

RELATIVE EFFICIENCY OF PROCESSES.

Comparatively little has been published regarding the efficiency and economy of salt-making processes. According to Merrill,^a a kettle block can produce 2,520 pounds of salt from 67° brine (salimeter reading) for each ton of anthracite dust used as fuel, and 4,088 pounds from 96° brine, these figures corresponding to evaporation efficiencies of 5.83 and 6 pounds of water per pound of fuel. Chatard,^b selecting the best results of the various systems, concludes that 1 pound of coal evaporates 5.72 pounds of water in the direct-heat open-pan process, 6.47 pounds of water in the high-pressure grainer process, and 7.69 pounds in the low-pressure grainer process followed in the Kanawha district (see pp. 77-79). Willcox^c calculates from the results of a careful run in a Michigan grainer an evaporation efficiency of 8.322 pounds of water per pound of coal. So many factors, however, affect such statements of efficiency that the figures quoted are unsafe criteria for comparison. The concentration and composition of the brine, the nature and heat value of the fuel, atmospheric conditions, and other conditions make analysis of the problem difficult. Ease of operation, low cost of maintenance, dependability, simplicity of construction, and means of meeting and overcoming unexpected difficulties are among the factors that give an evaporator the best all-round efficiency. An attempt was made by the writer to procure new data on the unit cost of making salt, but so few and so diverse replies were received that compilation or comparison was impracticable, and consequently this phase of the industry has necessarily been left for consideration at some future time. It is greatly to be hoped that salt manufacturers may publish data relating to this subject.

The experiments by Willcox,^d to which reference has been made, represent so extensive an analysis of the grainer process that his report of the results of them have been abstracted. The test was run in Michigan under normal working conditions on a grainer equipped with submerged mechanical rakers and heated by exhaust steam that entered at an average temperature of 216.6° F., and had an average quality of 97 per cent. The grainer was 143 feet long and 10.67 feet wide at the average level and was filled with brine to an average depth of 1.229 feet. It contained 1,072 feet of 3.5-inch pipe, the ratio of the evaporating (grainer) area to the heating surface being 1.34. The brine at 92.5 per cent saturation was run into the grainer at a temperature of 71.6° F. and the test was continuous for 192

^a Merrill, F. J. H., *Salt and gypsum industries of New York*: N. Y. State Mus. Bull., vol. 3, No. 11, 1893, p. 65.

^b Chatard, T. M., *Salt-making processes in the United States*: U. S. Geol. Survey Seventh Ann. Rept., 1896, p. 526.

^c Willcox, G. B., *Evaporation tests of a salt grainer*: Michigan Engineer, 1907, p. 168.

^d Willcox, G. B., place quoted.

hours, at the end of which time the saturation of the bittarn unduly impeded evaporation. At the start, evaporation was continued till the level of the brine had lowered nearly to the steam pipes in the grainer. The quantity evaporated was then restored by introducing new brine, and this process of alternate evaporating and filling was continued throughout the test. The results of the run are summarized in the following tables:

Results of operating a grainer in Michigan for 192 hours.

Item.	Pounds.
Total production of hot salt.....	110,950
Production of hot salt per hour.....	577.8
Equivalent in seasoned packed salt per hour.....	^a 534.5
Total condensation of water from grainer pipes.....	410,368
Condensation per hour.....	2,137
Equivalent condensation of dry steam per hour.....	^b 2,073
Production of hot salt per square foot of grainer surface.....	72.7
Production of hot salt per square foot of heating surface.....	97.9
Production of hot salt per linear foot of 3.5-inch steam pipe.....	102.5
Production of hot salt per cubic foot of brine.....	13.46
Condensation of dry steam per cubic foot of brine.....	46.8

Volume of steam condensed and quantity of hot salt produced during successive periods of approximately uniform production.

Duration of period.	Total during period.		Rate per hour during period.		Steam required to produce 1 pound of hot salt.
	Hot salt produced.	Steam condensed.	Hot salt produced.	Steam condensed.	
Hours.	Pounds. (^a)	Pounds.	Pounds.	Pounds.	Pounds.
9		26,320		2,924	
37	29,297	91,354	684	2,466	3.605
53	32,966	110,670	623	2,066	3.348
17.5	11,783	39,296	673	2,245	3.336
34.5	20,896	69,286	605	2,008	3.01
4	2,468	7,594	617	1,898	3.076
24	10,640	46,452	442	1,477	3.18
13	6,900	24,040	531	1,849	3.49
192	114,950	414,012			

^a Production sufficient only to fill the "clearance" on the bottom of the grainer.

Willcox^c calculates that the efficiency represented by these figures corresponds approximately to the evaporation of 8.322 pounds of water by 1 pound of coal. He adds that in the usual operation of this grainer the bittarn is replaced by new brine every 5 days, 2 hours being lost at each filling, and that the services of 4 men for 3 hours are required to scale the pipes every 30 days.

^a One pound of hot salt is equivalent to 0.925 pound of seasoned packed salt.

^b The steam contained 3 per cent moisture.

^c Willcox, G. B., place quoted.

TECHNOLOGY OF MINING AND MILLING OF ROCK SALT.^a**SITUATION AND DEVELOPMENT OF MINES.**

Rock salt was first discovered in North America, so far as is known, at Petite Anse, La., in 1862, and it is still mined there and also at Grande Cote, near by. Though its existence in New York and Michigan has been known for many years, it is mined in New York only by the Retsof Mining Co., at Retsof, and the Sterling Salt Co., at Halite, and in Michigan only by the Detroit Salt Co., at Detroit.

The beds of rock salt in Kansas were discovered in 1887 and 1888, during drilling operations for oil and gas, at Ellsworth, Lyons, Hutchinson, Great Bend, Kanopolis, Sterling, Kingman, Anthony, and Wellington. The salt-bearing series ranges in thickness from place to place from 50 to more than 400 feet.

Rock salt in Kansas has been produced, to any extent, at only five mines, and these have been operated by the Kingman Salt Co., Kingman, the Crystal Rock Salt Co., The Independent Salt Co., and the Royal Salt Co., at Kanopolis, and the Bevis Rock Salt Co., at Lyons. In 1915 the four companies last named were engaged in active mining. The Bevis Rock Salt Co. began to hoist salt in 1890 and has been operating continuously since. The shaft of the Royal Salt Co. was sunk in 1891; the mine has been operated only part of the time since then, but at present it is being worked. The shaft of the Crystal Rock Salt Co. was sunk in 1908, and the mine has been in operation since. The first production of the Independent Salt Co. was in 1914. Shafts have been started at Ellsworth, Marquette, and Little River, but for various reasons the work has been abandoned.^b

RETSOF MINING CO., RETSOF, N. Y.**MINING.**

The shaft of the Retsof Mining Co., Retsof, N. Y., is 1,017 feet deep, and it passes through the following beds:

Section of main hoisting shaft No. 1, Retsof Mining Co., Retsof, N. Y.

Material.	Thickness, feet.	Depth, feet.
Shale.....	133	.....
Limestone.....	8	141
Shale.....	232	373
Limestone.....	4	377
Shale.....	23	400
Lime.....	3	403
Corniferous limestone.....	142	545
Cement.....	13	558

^a The descriptions are based on observations made in 1911. The writer has not had any opportunity to visit the field and to verify them since that year.

^b Young, C. M., Rock salt mining operations in central Kansas: Mining World, vol. 34, 1911, p. 1223.

Material.	Thickness, feet.	Depth, feet.
Sandstone.....	4	562
Cement.....	7	569
Sandstone.....	14	583
Gypsum.....	4	587
Cement.....	26	613
Gypsum.....	47	660
Magnesian lime and sands	63	723
Cement.....	14	737
Blue shale.....	25	762
Cement.....	10	772
Blue shale.....	12	784
Helderberg cement.....	17	801
Mixture.....	31	832
Cement.....	10	842
Lime, cement, and sand.....	15	857
Cement.....	6	863
Blue shale.....	19	882
Red shale.....	12	894
Blue shale.....	41	935
Red shale.....	5	940
Blue shale.....	12	952
Lime.....	12	964
Salt and shale.....	32	996
Foot of shaft		1,017

The salt bed that is being worked is 8 feet thick, but rolls pinch it to a thickness of 5 feet locally. Great care is exercised not to break into the roof or to pick up the floor. Drilling is done with 1½-inch auger drills, operated by 3½-horsepower electric motors. The rooms are run 30 feet wide, and the net result of the mining is the removal of five-ninths of the salt, leaving four-ninths standing as square pillars, each side of each pillar being 30 feet long. The drilling is done at the room face, the end of the room being advanced in the form of a blunt wedge. The walls of the room are, of course, kept parallel during the advance of the mining. The salt is hauled by mules from the room face to the sidings but electric haulage is used from the main headings to the shaft. Mule power is used also for loading the salt into the cages.

MILLING.

The salt is hoisted in 3-ton mine cars from the foot of the shaft to the top of the mill, where the run-of-mine salt is dumped on grizzly or riddle bars made of cast steel and arranged in tiers. The finer salt falls through the grizzlies into a hopper, and most of the coarser part is crushed between large rolls though part of it is carried by conveyers to a storehouse, from which it is loaded on cars for shipment. The pieces of salt as they come from the mine are 1 foot or less in diameter. The subsequent operations consist of alternate screening and crushing, by which the desired market sizes are obtained.

Four market sizes are produced in New York in addition to the large lumps direct from the mine. These, beginning with the coarsest, are known as No. 2, No. 1, Coarse C. (common coarse, indicated by the letters "C. C."), and Fine C. (common fine, indicated by the letters "C. F."). These grades are illustrated in Plate XXIV (p. 130).

STERLING SALT CO., HALITE, N. Y.

The shaft of the Sterling Salt Co., at Cuylerville or Halite, N. Y., is approximately 1,150 feet deep. After the salt has been mined it is lifted in a 3-ton automatic dumping cage to the top of the mill and dumped on sets of grizzly bars. The fines drop through one set and the lumps drop through another set to crushers, and the larger hard lumps that are salable descend through a zigzag chute to be loaded for shipment. The fines from the crushers and from the grizzlies pass through the main hopper beneath the grizzlies to three shaking screens, arranged in decks, one screen above another, with the coarsest at the top.

The material that does not pass through the coarsest screen is diverted through a spout to a picking table (size 4). The material that passes through the first screen and over the second goes to a picking belt (size 3), where impurities are removed. Sizes 3 and 4 are not salable and are therefore crushed together and returned to the main hopper by a bucket conveyor. No. 2 grade is what passes through the upper two decks of the head screens but not through the third deck. The finer grade, which passes through the third deck of the head screen, is a mixture of No. 1, C. C., and C. F. This mixture is conveyed on belts to the tail screens. From the conveyor belt it is dropped into a hopper and thence diverted in spouts to tail screens. There are two decks to each set of these screens. The salt that fails to pass through the upper deck is known as grade 1; that which passes through the upper deck but does not pass through the lower deck is grade C. C.; that which passes through both screens is grade C. F. The operations of this mill are graphically shown in figure 9.

DETROIT SALT CO., DETROIT, MICH.

MINING.

The shaft of the Detroit Salt Co., Detroit, Mich., is 1,050 feet deep, with a 20-foot bed of salt at the bottom, of which 16 feet are worked by the room-and-pillar system, the rooms and entries being 35 feet wide and the pillars 40 feet square. The shaft is divided into three compartments, two of which are used for hoisting and one for supplying air, the foul air being removed through the hoisting compartments. The entire shaft is 9 by 18 feet, and in its present working condition each compartment is 5 by 5½ feet.

MILLING.

After the run-of-mine salt has been hoisted to the top of the mill the large lumps are conveyed to a storehouse for shipment. The fines and smaller lumps go through a grizzly and two toothed crushers. The fines are then removed by a screen and separated into four

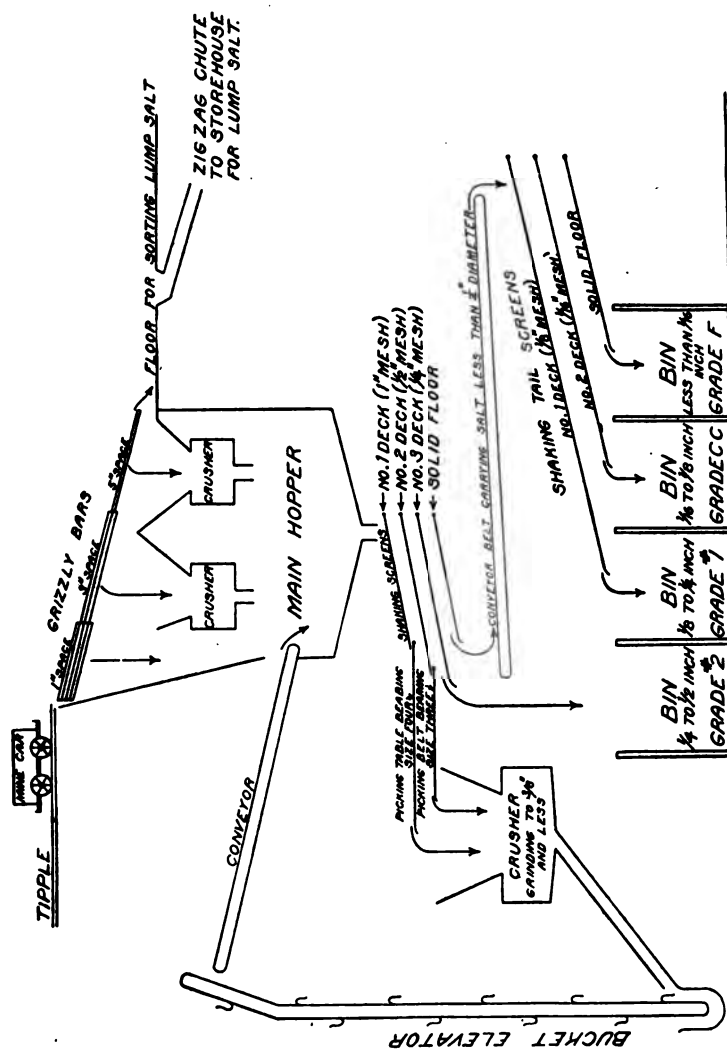


FIGURE 9.—Flow sheet of milling process used in preparing rock salt for market.

marketable sizes (No. 2, No. 1, C. C., and C. F. grades). The oversize material is picked to remove foreign material and discolored salt. This oversize material, constituting about 70 per cent of the run, is then crushed between corrugated rolls and elevated to another screen, and the four marketable sizes are again separated. The

oversize or coarse salt from the second scalping screen goes through a small disk mill and the fine salt thus obtained is separated into the four marketable sizes.

BEVIS ROCK SALT CO., LYONS, KANS.^a

METHOD OF SINKING SHAFT.

The shaft and plant of the Bevis Rock Salt Co., Lyons, Kans., were constructed under the direction of Mr. Jesse Ainsworth in 1890.

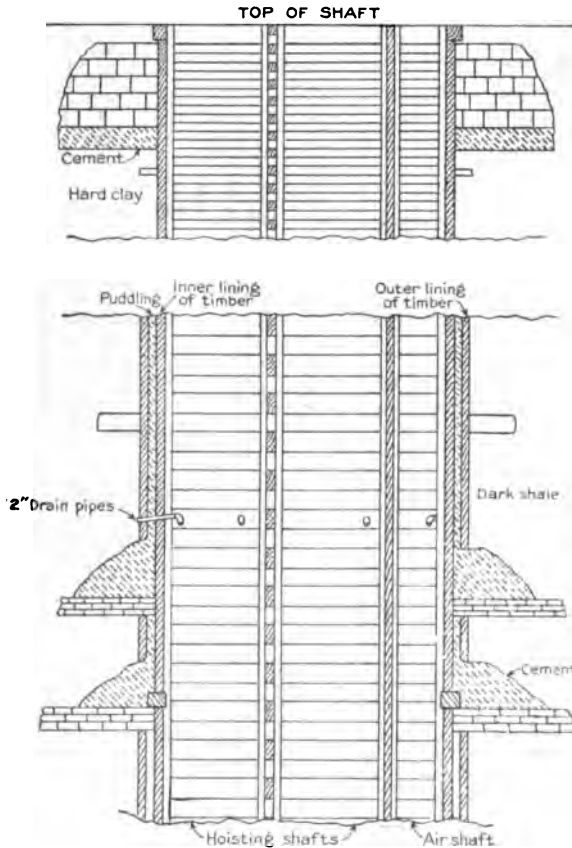


FIGURE 10.—Section showing method of sinking shaft through water-bearing stratum at Bevis salt plant, Lyons, Kans.

soluble material below, it was necessary to shut out this water. The shaft was, therefore, enlarged at this point to 9 feet 6 inches by 17 feet 10 inches to allow for an outer and an inner lining with puddling between to keep the water out of the shaft. As sinking progressed, the outside lining was carried down and firmly

The shaft is situated approximately in the center of a large acreage of salt land controlled by the company and contains two hoisting compartments, each 6 by 7 feet, and one ventilating compartment, 3 by 7 feet, inside dimensions. A stone and concrete foundation protects the mouth of the shaft and supports the headframe (fig. 10). The first 30 feet of the shaft through hard clay free from water is timbered with 6 by 6 inch pine timbers. The next 30 feet is in sandy clay yielding more than 500 gallons of water an hour. As there are about 300 feet of

^a The writer is greatly indebted to Mr. Sam Ainsworth for much of the information here given regarding salt mining in Kansas. Data from Mr. Ainsworth have been supplemented by personal observation.

held in place by temporary buntons, or crosswise timbers. Double corner strips were put on, and each twelfth set of 4 by 12 inch timbers was used as drift timbers.

A stratum of dark shale containing thin layers of limestone was encountered at a depth of 60 feet, and the shaft was cut by hand through it. Ten feet below the top of this shale the dimensions of the shaft were increased 4 feet on all sides, the space tapering at an angle of 45°. This space was timbered and filled with cement. Eight 2-inch pipes were inserted through the timbers immediately above the cement to carry the water into the shaft while the cement was being placed. A second cement ring was put in 6 feet below the first ring. Heavy 12 by 12 inch drift timbers were placed, and a 4-inch lining was started inside of these, the space behind it being filled with cement. (See fig. 10.)

The eight drain pipes were just long enough to extend through holes in the lining. The temporary buntons were taken out, a few at a time, and replaced with permanent ones. When cement had been run between the two linings a 15-inch water-tight wall was formed. After the shaft had been timbered in this way up to 5 feet above the water-bearing stratum and the pipes had been plugged the shaft became perfectly dry. From this point to the bottom the shaft was timbered with 4 by 12 inch timbers placed "skin to skin" edgewise. A red water-bearing sandstone was encountered at 130 feet, and a water ring was put in below it, holding the accumulation for 8 or 10 days. Below this point no further trouble was caused by water. When salt was struck the inside dimensions of the shaft were increased to 17 feet by 8 feet 8 inches to provide space for an inner lining and puddling should it be found necessary to keep water from the salt.

Fourteen workable seams of salt were penetrated and it was decided to work an 18-foot bed near the bottom of the deposit. The shaft is 1,075 feet deep, the last 10 feet being a sump, though it is reported that no water has been hoisted from the mine during the 19 years it has been in operation.

MINING.

Two main entries were driven east and west from the bottom of the shaft, and rooms and tunnels were started from them, crosscuts being driven at right angles to the tunnels every 50 or 75 feet. Rooms are then driven, and the pillars left standing are about 50 feet wide and 17 feet high. No timbers are used in this mine and the roof is reported to be good, all the workings remaining clear of falling rock.

Heavy auger drills operated by compressed air are used in mining the salt. The salt is first undercut to a depth of about 3.5 feet. Twenty per cent nitroglycerin powder is used, and all the holes in

a room are fired simultaneously by electricity. The blasts are large, 500 tons of rock often being shot down at one blast. The salt is loaded into mine cars and hauled to the shaft by mules.

The salt seam mined is 18 feet thick and is closely uniform. About 6 inches of it are left as a floor and 12 to 18 inches are left as a roof. Thus the mine has a solid salt floor and roof and no shale has to be picked out of the salt. The seam dips southwest, but the dip is so slight that the workings are considered level. About 3 to 4 acres are mined out each year.

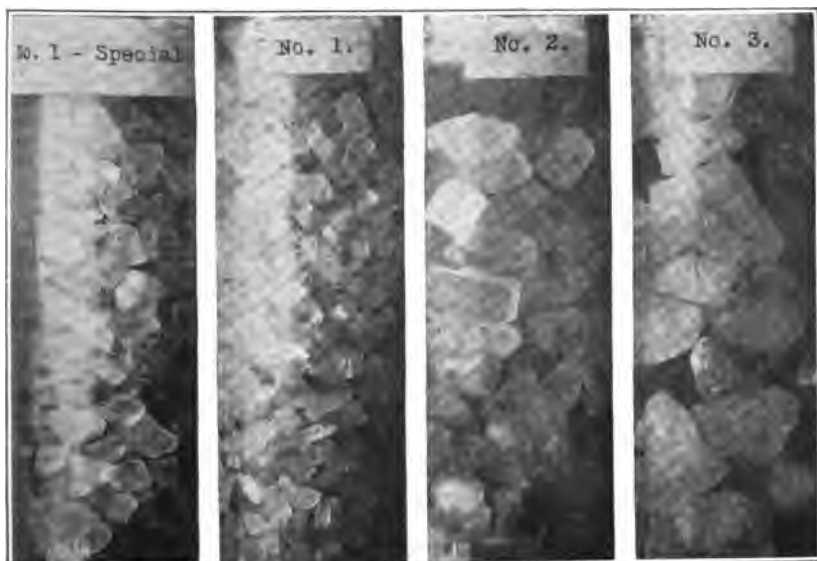
MILLING.

The company has two mills, both being used only when a large output is demanded. As the mills are alike, a description of one suffices. The salt hoisted from the mine is dumped from the cars into a hopper and is fed through a gate between toothed rolls. The large lumps are prevented from going to the rolls by bars over them and are diverted through a chute to a storeroom. After the salt has passed between the rolls it goes to a shaker, through which the fines pass. The oversize material goes to a set of corrugated rolls and from them the salt goes to a pair of shakers, which divide it into four grades, oversize, No. 2, No. 3, and C. F. The C. F. salt is elevated to a pair of impact screens, by which it is divided into grades 1, 7, and 4, which go to the bins. Grades 2 and 3 also go to the bins and the oversize goes back to the rolls to be reground.

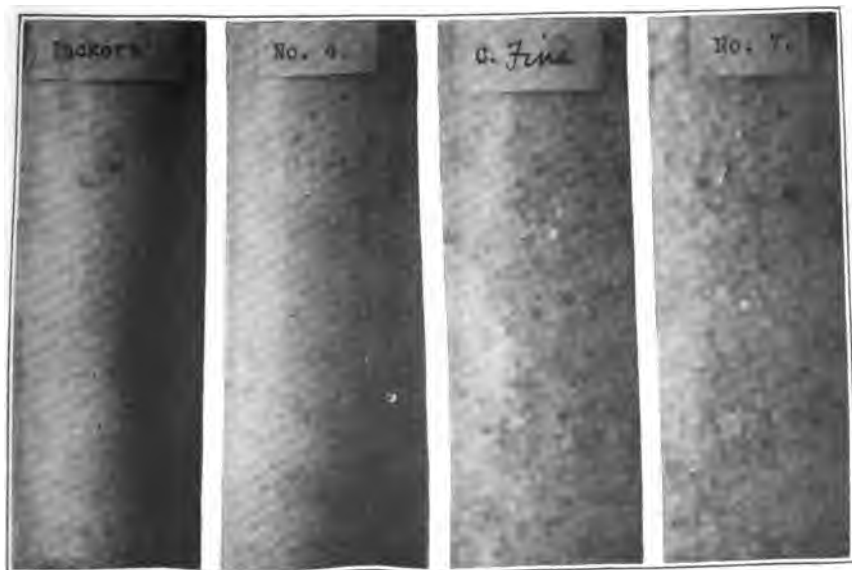
A small portion of the C. F. grade is sent to a centrifugal "cyclone" crusher, and the crushed product is sent to a pair of revolving screens. The oversize is mixed again with the C. F. salt and the fine salt, or "packers' fine," is sent to the bins. The other sizes may also be ground in the centrifugal crusher, and it is customary to grind sizes of salt for which there is little demand into packers' fine.

EQUIPMENT.

The mine is equipped with five boilers fired with fuel oil; about 600 horsepower is necessary to run the plant, the mill being operated by a 150-horsepower Corliss engine. The hoisting is done with a straight-line Litchfield hoist, the speed being about 2,650 feet a minute. The drum is flat, the cable is steel, 1½ inches in diameter, and the sheave wheels are 8 feet in diameter. The compressed air for the mines is furnished by a large two-stage Ingersoll-Sargeant compressor and is delivered to the mining machines at about 100 pounds pressure. The mine fan, which is an 18-foot exhaust fan of the Guibal type, is operated by an independent steam engine. The mine has a capacity of about 1,000 tons a day, but 700 tons of salt is about the daily maximum hoisted.



A. COARSER GRADES OF ROCK SALT PRODUCED IN KANSAS ROCK SALT MINES. GRAINS ABOUT SIX-SEVENTHS OF ORIGINAL SIZE.



B. FINER GRADES OF ROCK SALT PRODUCED IN THE KANSAS ROCK SALT MINES. ABOUT SIX-SEVENTHS OF ORIGINAL SIZE.

ROYAL SALT CO., KANOPOLIS, KANS.

The shaft of the Royal Salt Co. (Pl. X, *C*, p. 52), constructed in 1890, is about one-quarter mile from Kanopolis, Ellsworth County, Kans. In 1912 water was being pumped from a ring in the shaft at a depth of 210 feet. The timbers of the shaft are held in place by a series of props to the side walls of the area where the salt has been washed away, and the timbering has been tied together with flooring. The shaft contains two hoisting compartments, each 5.5 by 6.5 feet, and an air compartment 8 by 6.5 feet, and it is 803 feet deep. The bed of salt mined is 9 feet thick.

MINING.

Two main entries 40 feet wide have been driven north and south, and the mine is worked on a three-heading system, with all entries the same width. Compressed-air auger drills are used and 9-foot holes are bored. No undercutters are used and the salt is blasted off the solid. The powder used is a 20 per cent nitroglycerin powder, and it is exploded by electricity. As the roof and floor are tough gray shale, no timbers are deemed necessary.

The salt is loaded into mine cars holding 1 ton to 1.5 tons. The cars are hauled to the shaft by mules and hoisted to the top of the mill placed over the shaft. The seam of salt is uniform to the west and south, but not so much so to the east and north. It dips northeast in one part of the mine, but the dip is not great enough to hinder hauling.

MILLING.

Eight grades of salt are made in the mill: Nos. 1 special, 1, 2, 3, 4, 7, C. F., and packers' fine. Lump salt is also sold. These grades are like those illustrated in Plate XXIV.

The salt is dumped at the top of the mill onto a set of bars and all fine salt passes through to a 3-screen shaker. The large lumps may go by the lump conveyor to a storeroom or between 24-inch by 30-inch toothed rolls. From the rolls it goes between a second pair of toothed rolls, set closer together, and from that pair it goes to three fine-screen shakers. The shakers are narrow and contain wire screens, whereas those at the Bevis mill are wide and have punched-plate screens. The products of the shakers go to bins and elevators. There are also three fine grinders, and grades 2 and 3 are fed to them when there is a demand for fine salt from these grinders, being screened and then binned. The mill can handle about 250 tons of rock salt a day.

EQUIPMENT.

The plant has one sacking room and a lump storeroom. The steam for the hoisting engine, compressor, mill engine, fan engine,

and pumps is furnished by five oil-fired boilers of 100 horsepower each. The hoisting engine is a Vulcan hoist with a conical drum 7.5 feet in diameter at the small end and 10.5 feet in diameter at the middle. The 16-inch by 18-inch single-stage Ingersoll compressor delivers air at 100 pounds pressure. The mill is operated by a Buckeye Corliss engine of about 100 horsepower. An exhaust fan over the air shaft is operated by a separate steam engine.

CRYSTAL ROCK SALT CO., KANOPOLIS, KANS.

THE SALT BED.

The salt bed that is worked by the Crystal Rock Salt Co. at Kanopolis, Kans., is 11 feet thick and is capped by a layer of shale one-eighth inch thick. The bed is about 170 feet below the top of the first salt bed encountered in sinking the shaft, as will be seen from the following section:

Section of salt beds above the rock salt mined by the Crystal Rock Salt Co., Kanopolis, Kans.

Material.	Thickness. Ft. In.		Depth. Ft. In.	
Unrecorded strata to top of salt.	(612)		...	
Salt with black flakes, quite dark.	10		..	
Shale.	1		11	
Fair salt.	3		14	
Salt mixed with shale.	4		18	
Fair salt with dirt.	6		24	
Parting shale.	0	2	24	2
Fair salt.	5		29	2
Shale.	1	6	30	8
Salt and dirt mixed.	6		36	8
Dirt.	0	3	36	11
Fair salt.	3	6	40	5
Shale.	0	2	40	7
Good salt.	4		44	7
Shale.	1		45	7
Salt and shale mixed.	4		49	7
Fair salt.	4		53	7
Black flakes and salt mixed.	20		73	7
Shale.	0	8	74	3
Dirty salt.	7		81	3
Shale.	1		82	3
Fair salt.	3		85	3
Shale.	1	6	86	9
Fair salt.	2		88	9
Shale.	2		90	9
Dirty salt.	11		101	9
Shale.	1		102	9
Fair salt.	3		105	9
Salt and shale mixed.	0	10	106	7
Clay.	7		113	7
Salt and shale mixed.	9		122	7
Hard black salt.	0	8	123	3
Good salt with black streaks running up and down.	8		131	3

Material.	Thickness.		Depth.	
	Ft.	In.	Ft.	In.
Fair salt.....	4		135	3
Salt and shale mixed.....	1	6	136	9
Fair salt with dark streaks.....	6		142	9
Shale.....	1		143	9
Dark salt.....	7	6	151	3
Parting.....	0	1	151	4
Dark salt.....	1	3	152	7
Parting.....	0	1	152	8
Dark salt.....	1	6	154	2
Good salt.....	3		157	2
Black salt.....	0	6	157	8
Fair salt.....	5	6	163	2
Shale.....	0	2	163	4
Good salt.....	1	8	165	
Fair salt.....	3		168	
Streaked black salt.....	2	6	170	6
Salt (now being worked).....	11		181	6

The section does not show the entire thickness of the salt-bearing series, as a prospecting shaft known as No. 3 shaft has been sunk nearly 50 feet deeper in the search for potash salts. The section revealed by this deeper shaft is given below:

Section of Shaft No. 3, Crystal Rock Salt Co., Kanopolis, Kans.

Material.	Thickness.		Depth.	
	Ft.	In.	Ft.	In.
Shale.....	0	10	...	
Dark salt.....	5		5	10
Shale.....	0	2	6	
Dark salt.....	1	10	7	10
Shale.....	0	1	7	11
Dark salt mixed with shale.....	15		22	11
Shale.....	0	1	23	
Dark salt.....	1	4	24	4
Shale.....	8		32	4
Dark salt.....	4		36	4
Shale.....	0	1	36	5
Light-colored salt.....	3	6	39	11
Shale.....	0	1	40	
Light-colored salt.....	6	10	46	10

Thus if the thickness of the salt bed that is being worked is taken as 11 feet the total thickness of salt and associated beds is about 228 feet, and the sections given above do not include the entire saline series. Of the sections given above, 188 feet 11 inches is salt designated as fair, good, dirty, or mixed with other ingredients. The shaft was sunk in 1907 and 1908. It is about one-quarter mile southwest of that of the Royal Salt Co.

METHOD OF SINKING SHAFT.

The shaft is a three-compartment shaft, 6.5 by 18 feet inside dimensions, two of its compartments being used for hoisting and the

third for an air shaft. The shaft was timbered down to the first water level with heavy timbers, and a large drum of boiler iron, the shape of the shaft, was driven through the water-bearing sand. The drum is bracketed and timbered on the inside to prevent its collapsing. It was driven into a seam of clay below the sand, and the shaft below the clay seam is timbered with heavy timbers set "skin to skin." Two other small water-bearing strata were encountered and a water ring was inserted at a depth of about 300 feet, from which water is being pumped.

The shaft is 800 feet deep and strikes the same seam of salt as that mined by the Royal Salt Co. The workings extend only a few hundred feet from the shaft.

MINING.

The mining operations are similar to those in the Royal mine. Electric drills were tried but they did not prove satisfactory and compressed-air auger drills are now used. The mine cars hold 2 tons and are trammed by hand.

MILLING.

The milling processes are similar to those in the mill of the Royal Salt Co., the main differences being that the Crystal mill is double, the cages are self-dumping, and the machinery is more compact. The same grades of salt are made. About 600 tons of salt can be crushed in a day with both mills running, but in 1912 only one mill was operated, and about 250 tons of salt was ground daily.

EQUIPMENT.

The mine has one sacking room below the bins and a lump store-room. The plant has three coal-fired boilers of 100 horsepower each, and all of them are used when the plant is in operation. The hoist is a direct-connected Crawford hoist with a cylindrical drum; the hoisting speed is 2,500 feet a minute. The compressor is a single-stage, belt-driven machine. A direct-current generator is used when the electric drills are operated. The mill, compressor, and generator are operated by a steam engine. No fan has been put in as the mine has been operated for only a short time.

COMMERCIAL GRADES OF KANSAS ROCK SALT.

The same grades of salt are produced at all the mines in Kansas and are given the same names in different parts of the State. The principal grades are numbered 1, 2, 3, 4, 7, C. F. (common fine), packers' fine, and lump salt. Grade No. 2, of which most is sold, is composed of cubes one-eighth to one-quarter inch in diameter and is extensively used for making brines in packing houses and for salting hides. Grade No. 1 consists of grains about the size of grains

of wheat. This salt is also used for salting hides, in manufacturing soda ash and caustic soda, in making brines and freezing mixtures, and in soap making. Grade No. 3 is coarse, the grains being more than one-quarter inch in diameter. This salt is used in refrigerator cars and in other refrigerators. Grade No. 4 is about as fine as coarse evaporated salt, and it is used by stockmen, soap makers, and glass manufacturers and also in chlorination furnaces. Grade C. F. contains all grades from No. 1 to the coarsest and it is used for about the same purposes as No. 1. Packers' fine is the finest grade made. It can be used for domestic purposes and it is used extensively in packing beef and pork. Lump salt is obtainable at all the mines, some lumps weighing several thousand pounds being sold. Lump salt is gray and firm. It is sold for salting live stock.

MYLES SALT CO., GRANDE COTE, LA.

According to Veatch^a salt was discovered at Grande Cote, La., in 1897, and nearly a year later the Myles Salt Co. was organized. The present shaft was commenced in July, 1898, where the salt is nearest the surface. One hundred feet of 10-foot tubular casing was used in sinking the shaft to the salt. In July, 1901, the work of sinking a rectangular shaft below this casing into the rock salt was begun. The 600-foot level was reached and tunnels to the east and the west were being driven in March, 1902. The shaft is 645 feet deep. The tubular casing was continued 10 feet into the rock salt. The shaft was continued in cylindrical form 35 feet farther, and wood lagging inclosed by concrete a foot thick was used to prevent leaking. This structure was encircled at intervals by rings of asphalt 3 to 5 feet high and 2 or 3 feet thick at the base. The surface of the salt after being thoroughly heated was painted with asphalt. The shaft below the 135-foot cylindrical section is 10 feet square.

Mining is carried on by first undercutting or blasting out triangular chunks of salt on a level with the floor of the mine. The overlying layers are then removed in turn upward from the floor. The salt is conveyed to the foot of the shaft in small dump cars drawn by mules over narrow-gage steel tracks. At the shaft the salt passes through a crusher, from which it falls into a bin. From the bin it is drawn off into a 5-ton self-dumping cage, in which it is drawn to the surface, the cage making the round trip in four minutes. A pair of 20-foot by 30-foot engines wind up the cable that lifts the cage. Two compressors supply air to the drills in the mine, and a small separate engine works the ventilating fans. The crusher at the bottom of the shaft, the screens, and the mill machinery above ground are run by electricity from a dynamo in the engine room. The salt is ground after being dumped from the cage on the top

^a Veatch, A. C., General geology: Louisiana Geol. Survey Rept. for 1899, pt. 5, 1899, p. 125.

floor of the building. It is then passed through screens of various mesh, depending on the sizes of salt marketed. Grades 1, 2, and 3 are used for refrigerating, curing hides, curing fish, making salt pickles, and glazing in enameling and pipe works.

The C (coarse) and F (fine) grades are used for dry-salting meats and clearing oleomargarine, and in chemical processes. The A grade is a special one, finer than No. 1 and coarser than C. The D grade is also a special one, consisting of powdered salt from the grinding of any of the crushed grades in the mills, and it is used for any purpose where rapid solution is desired.

EVERY SALT MINING CO., PETITE ANSE, LA.

Rock salt was discovered at Petite Anse, La., by John M. Avery, May 6, 1862, and so far as known this was the first discovery of rock salt in North America. The salt was first quarried in a number of open pits, which were destroyed in 1863. The first shaft, 8 feet square, was sunk in 1867 to a depth of 83 feet; the depth was later increased to 90 feet, 58 feet of which was in solid rock salt. After the ownership of the property had rested with different companies it finally reverted to the New Iberia Salt Co. in 1886, and arrangements were made for a switch to the plant from the main line of the Southern Pacific Co. Operations were continued until 1896, when the mines reverted to the Avery family, and two years later the Avery Rock Salt Mining Co. was formed. This company sank a shaft southwest of the old mine on a new site where operations are now conducted. According to Harris^a the shaft of the Avery Salt Mining Co. is 21 feet by 10 feet and 518 feet deep. It is divided into two hoisting shafts and one ventilating shaft. The galleries are 30 feet wide and are run in two directions at right angles to each other, pillars 30 feet square being left as supports.

The salt is conveyed to the foot of the shaft in small cars drawn on a narrow-gage track by horses and mules. The cars are put on the platform of the cage, hoisted to the top floor of the mill, and dumped by hand. The heavy crushing is therefore done at the top of the mill instead of at the foot of the shaft as at Grande Cote. After preliminary crushing the salt is further ground, screened, and winnowed to drive off the salt dust, which tends to deliquesce and thus cement together the larger salt grains. The various grades of salt produced are similar to those produced at Grande Cote, and are used for substantially the same purposes. (See p. 135.)

^a Harris, G. D., Rock salt: Louisiana Geol. Survey Rept. for 1907, Bull. 7, 1908, p. 17.

USEFUL TABLES CONNECTED WITH THE SALT INDUSTRY.

In the following pages are given certain tables relating to (1) the solubility of sodium chloride and other salts; (2) the chlorine content, salinity, and specific gravity of sea water at various concentrations; (3) atomic weight of elements common in saline solutions; (4) factors for converting radicles to compounds; and (5) comprehensive conversion tables for salt solutions.

It is believed that these tables will prove of interest and value to all students of the chemistry of salines in general.

Solubility of certain salts.^a

Salt.	Temperature.	Amount of pure compound without water of crystallization.	
		Dissolved in 100 grams of water.	Dissolved in 100 c. c. of the solution.
	[°] C.	Grams.	Grams.
Sodium chloride (NaCl).....	0	35.7	.....
	10	35.8	.....
	25	36.12	.....
	50	37.0	.....
	100	39.8	.....
Sodium sulphate (Na ₂ SO ₄ .10H ₂ O).....	0	5.0	.....
	25	28.0	.....
Sodium sulphate (Na ₂ SO ₄ .7H ₂ O).....	0	19.5	.....
	25	53.0	.....
Sodium bromide (NaBr).....	0	66.0	.....
	20	77.0	.....
Sodium iodide (NaI.2H ₂ O).....	0	158.7	.....
	25	184.2	.....
Potassium chloride (KCl).....	0	27.6	.....
	25	35.5	.....
Potassium sulphate (K ₂ SO ₄).....	0	7.35	.....
	25	10.75	.....
Potassium bromide (KBr).....	0	53.5	.....
	25	67.7	.....
Potassium iodide (KI).....	0	127.5	.....
	25	148.0	.....
Calcium chloride (CaCl ₂ .6H ₂ O).....	0	59.5	.....
	20	91.0	.....
Calcium sulphate (CaSO ₄ .2H ₂ O).....	0	.....	0.1759
	25	.....	.2080
	25	.....	b.426
	25	.....	c.589
	25	.....	d.1620
	25	.....	e.1471
	25	.....	f.606
	25	.....	g.650
Magnesium sulphate (MgSO ₄ .7H ₂ O).....	0	26.9	.....
	25	38.5	.....
Magnesium chloride (MgCl ₂ .6H ₂ O).....	0	52.8	.....
	25	56.7	.....
Magnesium bromide (MgBr ₂ .6H ₂ O).....	0	91.9	.....
	25	97.6	.....
Magnesium iodide (MgI ₂ .8H ₂ O).....	25	.....	h 54.4

^a Seidell, Atherton, Handbook of solubilities, New York, 1907, pp. 235-264.

^b Solution containing 8.5 grams per liter of MgCl₂.

^c Solution containing 19.8 grams per liter of MgCl₂.

^d Solution containing 3.2 grams per liter of MgSO₄.

^e Solution containing 10.64 grams per liter of MgSO₄.

^f Solution containing 91.15 grams per liter of NaCl.

^g Solution containing 264.17 grams per liter of NaCl.

^h Dissolved in 100 grams of the aqueous solution.

Chlorine content, salinity, and specific gravity of sea water at various concentrations.^a

Chlorine per kilogram.	Salinity per kilogram.	Specific gravity (0/4°).	Chlorine per kilogram.	Salinity per kilogram.	Specific gravity (0/4°).
<i>Grams.</i>	<i>Grams.</i>		<i>Grams.</i>	<i>Grams.</i>	
1.00	1.84	1.00140	19.60	35.41	1.02846
2.00	3.64	1.00287	19.65	35.50	1.02853
3.00	5.45	1.00438	19.70	35.59	1.02860
4.00	7.25	1.00579	19.75	35.68	1.02867
5.00	9.06	1.00725	19.80	35.77	1.02875
6.00	10.86	1.00871	19.85	35.86	1.02882
7.00	12.67	1.01016	19.90	35.95	1.02889
8.00	14.47	1.01162	19.95	36.04	1.02896
9.00	16.28	1.01307	20.00	36.13	1.02904
10.00	18.08	1.01452	20.10	36.31	1.02918
11.00	19.89	1.01597	20.20	36.49	1.02933
12.00	21.69	1.01742	20.30	36.67	1.02947
13.00	23.50	1.01887	20.40	36.85	1.02962
14.00	25.30	1.02032	20.50	37.03	1.02977
15.00	27.11	1.02177	20.60	37.21	1.02991
16.00	28.91	1.02322	20.70	37.39	1.03006
17.00	30.72	1.02468	20.80	37.57	1.03020
18.00	32.52	1.02613	20.90	37.75	1.03035
19.00	34.33	1.02758	21.00	37.94	1.03049
19.10	34.51	1.02773	21.50	38.84	1.03122
19.20	34.69	1.02787	22.00	39.74	1.03195
19.30	34.87	1.02802	22.50	40.64	1.03268
19.40	35.05	1.02816	23.00	41.55	1.03341
19.50	35.23	1.02831			

^a Knudsen, Martin, Hydrographische Tabellen, Copenhagen, 1911.

Atomic weights of elements common in saline solutions.^a

Element.	Symbol.	Atomic weight.	Element.	Symbol.	Atomic weight.
Aluminum.....	Al	27.1	Magnesium.....	Mg	24.32
Boron.....	B	11.0	Oxygen.....	O	16.00
Bromine.....	Br	79.92	Phosphorus.....	P	31.04
Calcium.....	Ca	40.07	Potassium.....	K	39.10
Carbon.....	C	12.00	Silicon.....	Si	28.3
Chlorine.....	Cl	35.46	Sodium.....	Na	23.00
Iodine.....	I	126.92	Sulphur.....	S	32.07
Iron.....	Fe	55.84			

^a Annual Report of the International Committee on Atomic Weights, 1915; Jour. Am. Chem. Soc., vol. 36, 1914, p. 1585.

Factors for converting radicles to compounds.^a

Radicle.	Compound.	Factor.	Radicle.	Compound.	Factor.
Na.....	NaCl.....	2.538	Cl.....	NaCl.....	1.650
	Na ₂ O.....	1.347		KCl.....	2.103
	Na ₂ SO ₄	3.084		MgCl ₂	1.842
	Na ₂ SO ₄ .10H ₂ O.....	6.992		MgCl ₂ .6H ₂ O.....	2.887
	Na ₂ SO ₄ .7H ₂ O.....	5.820		CaCl ₂	1.585
	Na ₂ CO ₃	2.301		CaCl ₂ .6H ₂ O.....	3.090
	NaHCO ₃	3.647	Br.....	NaBr.....	1.288
	NaI.....	6.502		NaBr.2H ₂ O.....	1.739
	NaI.2H ₂ O.....	8.066		KBr.....	1.489
	NaBr.....	4.469		MgBr ₂	1.152
	NaBr.2H ₂ O.....	6.036		MgBr ₂ .6H ₂ O.....	1.828
K.....	KCl.....	1.906		CaBr ₂	1.251
	K ₂ O.....	1.204	I.....	NaI.....	1.182
	K ₂ SO ₄	2.228		NaI.2H ₂ O.....	1.466
	K ₂ CO ₃	1.767		KI.....	1.308
	KHCO ₃	2.560		MgI ₂	1.096
	KI.....	4.243		MgI ₂ .8H ₂ O.....	1.664
Mg.....	KBr.....	3.044	SO ₄	CaI ₂	1.158
	MgCl ₂	3.920		Na ₂ SO ₄	1.480
	MgCl ₂ .6H ₂ O.....	8.376		Na ₂ SO ₄ .10H ₂ O.....	3.355
	MgO.....	1.659		Na ₂ SO ₄ .7H ₂ O.....	2.792
	MgSO ₄	4.958		K ₂ SO ₄	1.814
	MgSO ₄ .7H ₂ O.....	10.151		MgSO ₄	1.253
	MgCO ₃	3.471		MgSO ₄ .7H ₂ O.....	2.565
	Mg(HCO ₃) ₂	6.028	CO ₃	CaSO ₄	1.417
	MgI ₂	11.449		CaSO ₄ .2H ₂ O.....	1.792
	MgI ₂ .8H ₂ O.....	17.385		Na ₂ CO ₃	1.768
	MgBr ₂	7.588		K ₂ CO ₃	2.304
	MgBr ₂ .6H ₂ O.....	12.035		CaCO ₃	1.668
Ca.....	CaCl ₂	2.769		MgCO ₃	1.405
	CaCl ₂ .6H ₂ O.....	5.467	HCO ₃ ...	NaHCO ₃	1.378
	CaO.....	1.399		KHCO ₃	1.641
	CaSO.....	3.398		Mg(HCO ₃) ₂	1.199
	CaSO ₄ .2H ₂ O.....	4.297		Ca(HCO ₃) ₂	1.328
	CaCO ₃	2.498			
	Ca(HCO ₃) ₂	4.045			
	CaI ₂	7.331			
	CaBr ₂	4.990			

^a Calculated by R. B. Dole, from Annual Report of the International Committee on Atomic Weights, 1907, which differ little from those of 1915.

Conversion tables for salt solutions.^a

Salt-meter degrees.	Baumé degrees.	Specific gravity.	Per cent of salt.	Weight of a gallon of this brine in pounds of 7,000 grains each.	Pounds of salt in a gallon of brine of 231 cubic inches.	Gallons of brine required for a bushel of salt.	Pounds of water to be evaporated to produce a bushel of salt.	Pounds of coal required to produce a bushel of salt, 1 pound of coal evaporating 8 pounds of water.	Bushels of salt that can be made with a ton of coal of 2,000 pounds.
1	0.26	1.002	0.265	8.247	0.022	2,531.40	21,076.00	3,512.67	0.569
2	.52	1.003	.530	8.356	.044	1,264.40	10,510.00	1,751.67	1.141
3	.78	1.006	.785	8.372	.066	841.30	6,988.02	1,164.67	1.717
4	1.04	1.007	1.060	8.389	.088	629.72	5,227.03	871.17	2.295
5	1.30	1.009	1.325	8.406	.111	502.77	4,170.41	695.06	2.877
6	1.56	1.010	1.590	8.414	.133	418.56	3,466.01	577.66	3.462
7	1.82	1.012	1.855	8.431	.156	358.06	2,962.87	493.81	4.050
8	2.08	1.014	2.120	8.447	.179	312.68	2,585.80	430.91	4.641
9	2.34	1.016	2.385	8.462	.201	277.39	2,292.00	382.00	5.235
10	2.60	1.017	2.650	8.472	.224	249.41	2,057.20	342.86	5.833
11	2.86	1.019	2.915	8.489	.247	226.29	1,865.09	310.84	6.434
12	3.12	1.021	3.180	8.506	.270	207.02	1,705.00	294.16	7.038
13	3.38	1.023	3.445	8.522	.293	190.72	1,569.54	261.59	7.645
14	3.64	1.026	3.710	8.539	.316	176.76	1,453.43	242.23	8.256
15	3.90	1.028	3.975	8.547	.339	164.81	1,352.80	225.46	8.870
16	4.16	1.030	4.240	8.564	.363	154.21	1,264.75	210.79	9.488
17	4.42	1.032	4.505	8.581	.386	144.86	1,187.06	197.84	10.108
18	4.68	1.034	4.770	8.597	.410	136.54	1,118.00	186.33	10.733
19	4.94	1.035	5.035	8.614	.433	129.11	1,056.21	176.03	11.361
20	5.20	1.035	5.300	8.622	.457	122.53	1,000.60	166.76	11.992
21	5.46	1.037	5.565	8.639	.480	116.47	950.28	158.38	12.627
22	5.72	1.039	5.830	8.656	.504	110.96	904.54	150.75	13.266
23	5.98	1.041	6.095	8.672	.528	105.93	862.78	143.79	13.908
24	6.24	1.043	6.360	8.689	.552	101.33	820.50	137.41	14.554
25	6.50	1.045	6.625	8.706	.576	97.09	789.28	131.54	15.203
26	6.76	1.046	6.890	8.714	.600	93.26	756.77	126.12	15.856
27	7.02	1.048	7.155	8.731	.624	89.64	726.66	121.11	16.513
28	7.28	1.050	7.420	8.747	.649	86.27	698.71	116.45	17.173
29	7.54	1.052	7.685	8.764	.673	83.14	672.69	112.11	17.838
30	7.80	1.054	7.950	8.781	.698	80.21	648.40	108.06	18.507
31	8.06	1.056	8.215	8.797	.722	77.48	625.67	104.27	19.179
32	8.32	1.058	8.480	8.814	.747	74.92	604.37	100.72	19.855
33	8.58	1.059	8.745	8.822	.771	72.55	584.36	97.39	20.535
34	8.84	1.061	9.010	8.839	.796	70.31	566.53	94.25	21.218
35	9.10	1.063	9.275	8.856	.821	68.17	547.77	91.29	21.906
36	9.36	1.065	9.540	8.872	.846	66.15	531.00	88.50	22.596
37	9.62	1.067	9.805	8.889	.871	64.24	515.13	85.85	23.294
38	9.88	1.069	10.070	8.905	.896	62.44	500.10	83.35	23.993
39	10.14	1.071	10.335	8.922	.922	60.72	485.84	80.97	24.699
40	10.40	1.073	10.600	8.939	.947	59.09	472.30	78.71	25.407
41	10.66	1.075	10.865	8.955	.973	57.54	459.41	76.56	26.120
42	10.92	1.077	11.130	8.972	.998	56.07	447.14	74.52	26.837
43	11.18	1.079	11.395	8.989	1.024	54.66	435.44	72.57	27.558
44	11.44	1.081	11.660	9.005	1.050	53.32	424.27	70.71	28.283
45	11.70	1.083	11.925	9.022	1.075	52.04	413.60	68.93	29.013
46	11.96	1.085	12.190	9.039	1.101	50.82	403.39	67.23	29.747
47	12.22	1.087	12.455	9.055	1.127	49.64	393.61	65.60	30.486
48	12.48	1.089	12.720	9.072	1.154	48.52	384.25	64.04	31.229
49	12.74	1.091	12.985	9.089	1.180	47.44	375.26	62.54	31.977
50	13.00	1.093	13.250	9.105	1.206	46.41	366.64	61.10	32.729
51	13.26	1.095	13.515	9.122	1.232	45.42	358.34	59.72	33.487
52	13.52	1.097	13.780	9.139	1.259	44.46	350.38	58.39	34.247
53	13.78	1.100	14.045	9.164	1.287	43.50	342.71	57.11	35.015
54	14.04	1.102	14.310	9.180	1.313	42.62	335.35	55.89	35.783
55	14.30	1.104	14.575	9.197	1.340	41.77	328.21	54.70	36.560
56	14.56	1.106	14.840	9.214	1.367	40.96	321.35	53.55	37.341
57	14.82	1.108	15.105	9.230	1.394	40.16	314.74	52.45	38.126
58	15.08	1.110	15.370	9.247	1.421	39.39	308.34	51.39	38.917
59	15.34	1.112	15.635	9.264	1.448	38.66	302.17	50.36	39.712
60	15.60	1.114	15.900	9.280	1.475	37.94	296.21	49.36	40.512
61	15.86	1.116	16.165	9.297	1.502	37.26	290.43	48.40	41.317
62	16.12	1.118	16.430	9.314	1.530	36.59	284.84	47.47	42.129
63	16.38	1.121	16.695	9.339	1.559	35.91	279.42	46.57	42.945
64	16.64	1.123	16.960	9.355	1.586	35.29	274.18	45.69	43.765
65	16.90	1.125	17.225	9.372	1.614	34.68	269.10	44.85	44.591
66	17.16	1.127	17.490	9.389	1.642	34.10	264.18	44.03	45.423
67	17.42	1.129	17.755	9.406	1.670	33.53	259.40	43.23	46.260
68	17.68	1.131	18.020	9.422	1.697	32.98	254.76	42.46	47.102

^a Englehardt, F. E., Annual report of Onondaga Salt Springs, for 1883, 1884, pp. 36-37.

Conversion tables for salt solutions—Continued.

Salt-meter degrees.	Baumé degrees.	Specific gravity.	Per cent of salt.	Weight of a gallon of this brine in pounds of 7,000 grains each.	Pounds of salt in a gallon of brine of 281 cubic inches.	Gallons of brine required for a bushel of salt.	Pounds of water to be evaporated to produce a bushel of salt.	Pounds of coal required to produce a bushel of salt, 1 pound of coal evaporating 6 pounds of water.	Bushels of salt that can be made with a ton of coal of 2,000 pounds.
69	17.94	1.133	18.285	9.439	1.725	32.44	250.26	41.71	47.949
70	18.20	1.136	18.550	9.464	1.755	31.89	245.88	40.96	48.802
71	18.46	1.138	18.815	9.480	1.783	31.89	241.63	40.27	49.662
72	18.72	1.140	19.080	9.497	1.812	30.90	237.50	39.58	50.526
73	18.98	1.142	19.345	9.514	1.840	30.42	233.47	38.91	51.397
74	19.24	1.144	19.610	9.530	1.868	29.96	229.56	38.26	52.272
75	19.50	1.147	19.875	9.555	1.899	29.48	225.76	37.62	53.153
76	19.76	1.149	20.140	9.572	1.927	29.04	222.05	37.00	54.041
77	20.02	1.151	20.405	9.580	1.956	28.62	218.44	36.40	54.934
78	20.28	1.154	20.670	9.614	1.967	28.17	214.92	35.82	55.834
79	20.54	1.156	20.935	9.630	2.016	27.77	211.49	35.24	56.739
80	20.80	1.158	21.200	9.647	2.045	27.38	208.14	34.69	57.650
81	21.06	1.160	21.465	9.664	2.074	26.99	204.88	34.14	58.568
82	21.32	1.163	21.730	9.689	2.105	26.59	201.70	33.61	59.471
83	21.58	1.165	21.995	9.705	2.134	26.23	198.60	33.10	60.421
84	21.84	1.167	22.260	9.722	2.164	25.87	195.57	32.59	61.359
85	22.10	1.170	22.525	9.747	2.195	25.50	192.61	32.10	62.301
86	22.36	1.172	22.790	9.764	2.225	25.16	189.72	31.62	63.250
87	22.62	1.175	23.055	9.780	2.256	24.81	186.89	31.14	64.206
88	22.88	1.177	23.320	9.805	2.286	24.48	184.13	30.68	65.168
89	23.14	1.179	23.585	9.822	2.316	24.17	181.44	30.24	66.137
90	23.40	1.182	23.850	9.847	2.348	23.84	178.80	29.80	67.113
91	23.66	1.184	24.115	9.864	2.378	23.54	176.22	29.37	68.096
92	23.92	1.186	24.380	9.880	2.408	23.24	173.69	28.94	69.085
93	24.18	1.189	24.645	9.905	2.441	22.96	171.22	28.53	70.086
94	24.44	1.191	24.910	9.922	2.471	22.65	168.80	28.13	71.086
95	24.70	1.194	25.175	9.947	2.504	22.36	166.44	27.73	72.105
96	24.96	1.196	25.440	9.964	2.534	22.00	164.12	27.35	73.114
97	25.22	1.198	25.705	9.980	2.565	21.82	161.85	26.97	74.140
98	25.48	1.201	25.970	10.005	2.598	21.55	159.63	26.60	75.172
99	25.74	1.203	26.235	10.022	2.629	21.29	157.45	26.24	76.212
100	26.00	1.205	26.500	10.039	2.660	21.04	155.32	25.88	77.259

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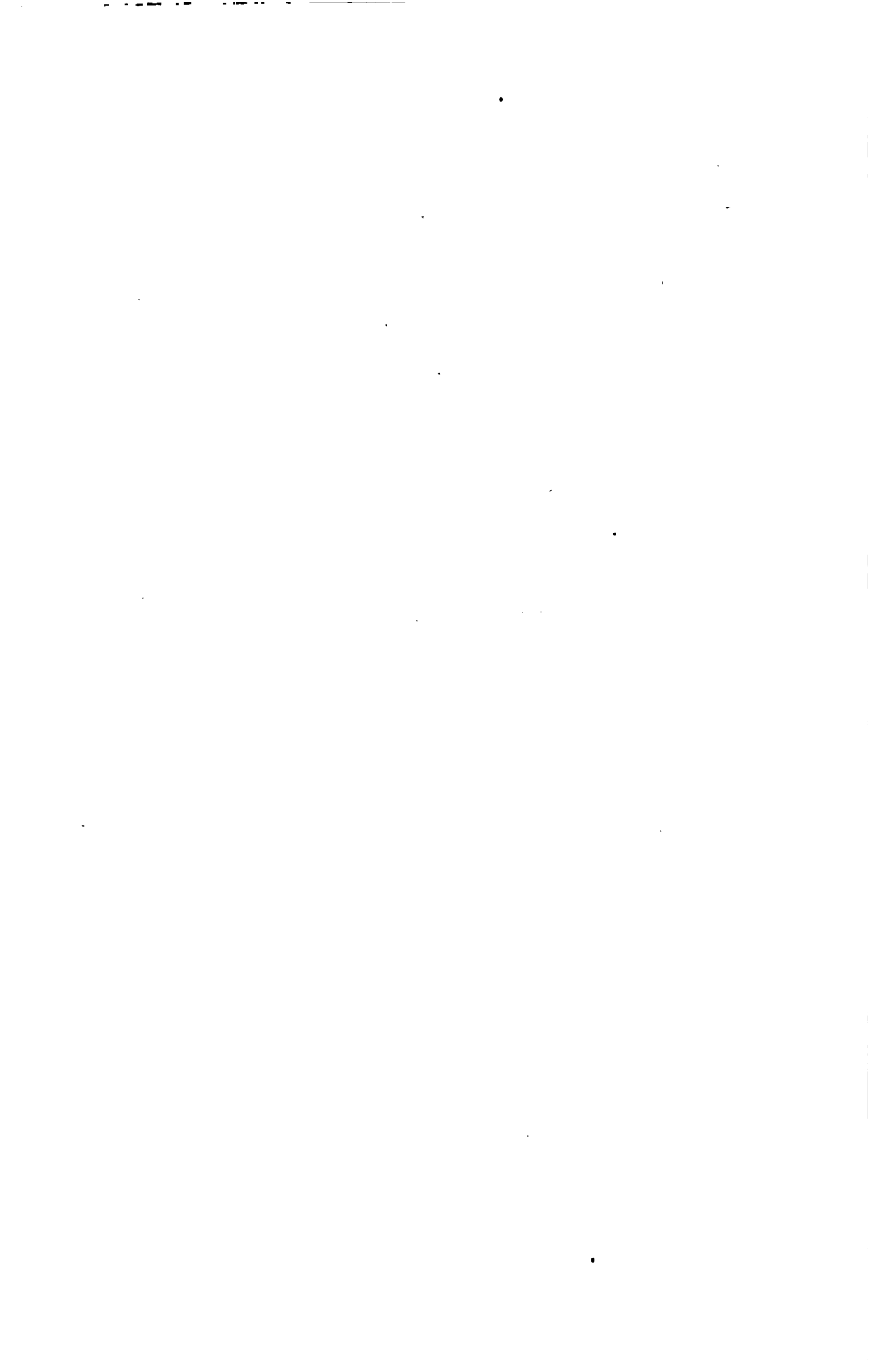
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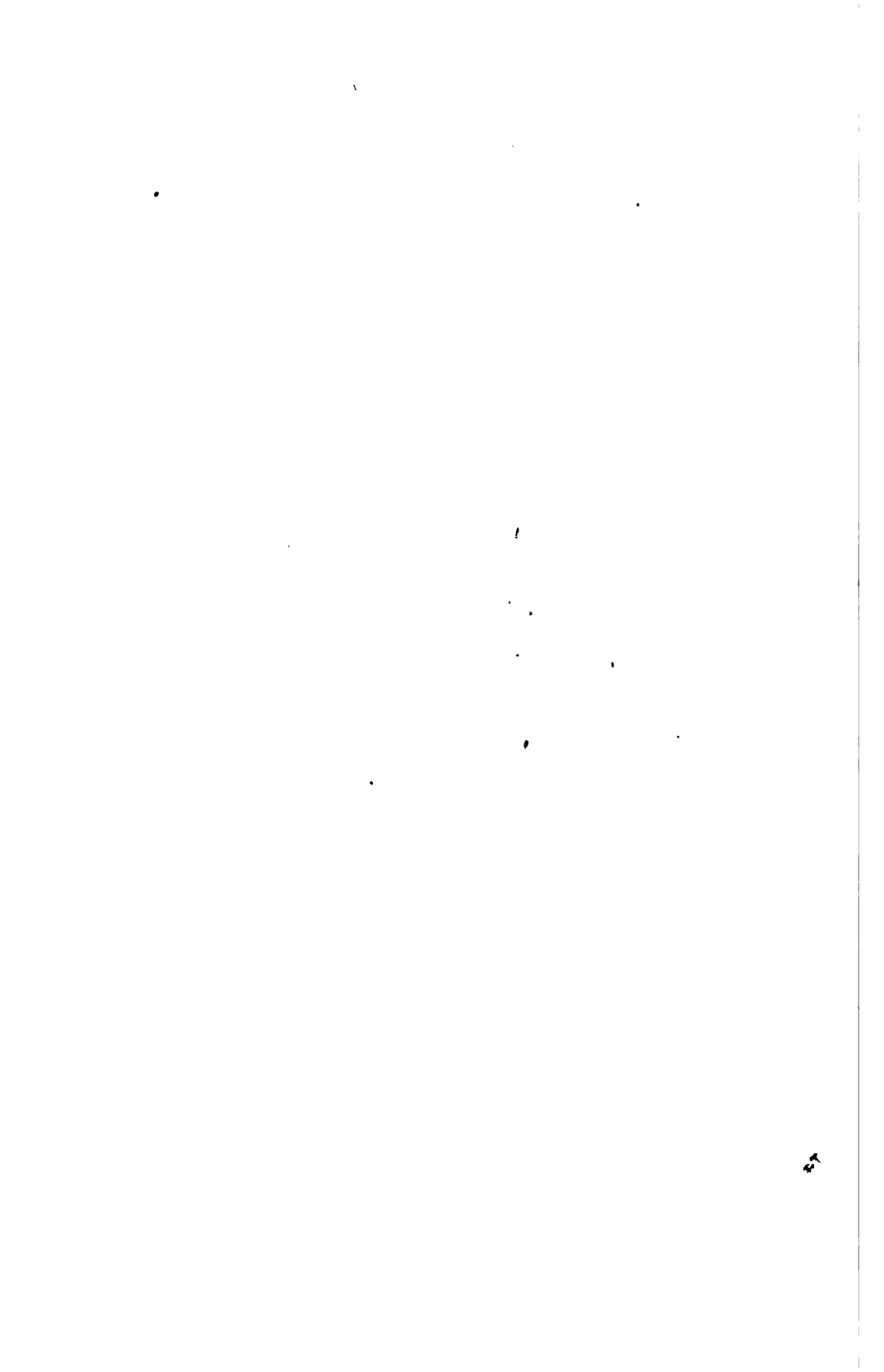
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**METHODS FOR INCREASING THE RECOVERY
FROM OIL SANDS**

BY

J. O. LEWIS



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METHODS FOR INCREASING THE RECOVERY FROM OIL SANDS.

By J. O. LEWIS.

INTRODUCTION.

In its efforts to reduce waste, and increase efficiency in oil production, the Bureau of Mines is investigating methods of increasing the recovery from the underground sources of supply, which are the foundation of the petroleum industry and the many allied industries wholly or partly dependent on it. In the face of a demand that is increasing faster than the production and that, in the consensus of opinions of well-informed authorities, is soon likely to outstrip the productive capacity, it is well to consider whether it is not possible to extract more oil from the known sources of supply. It is universally acknowledged that by the usual production methods much oil is left underground, the general opinion being that at least 50 per cent of the oil in a field remains unrecovered when the field is abandoned as exhausted. From the writer's own investigations he believes the average recovery is even less, and if any considerable portion of this oil being left underground could be made available it would have a tremendously favorable influence on the petroleum industry and all the industries dependent on it.

In this publication are considered the principles involved in increasing recovery and methods of extracting more oil from the oil-bearing formations than by the usual ways of producing. These methods are: The use of gas or vacuum pumps, forcing compressed air or gas through the oil-bearing formations, displacing the oil by water, and better utilization of the natural pressures in the oil-bearing formations. Especial attention is being given to a process—commonly known as the Smith-Dunn—for forcing compressed air through oil-bearing formations because it is believed to hold most promise for the future.

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GENERAL STATEMENT.

That much of the oil in a field is never recovered is well known, but how large a proportion is left underground and the possibility of increasing the recovery can not be fully realized until one clearly understands that the exhaustion of an oil well is due more to the exhaustion of the natural gas, which is the principal agent in driving the oil into the well, than to the exhaustion of the oil itself.

Facts presented in this bulletin go to show that the capacities of the oil sands in the various fields of the United States are five to ten times greater than the quantities of oil commonly extracted from them. If it could be fully established, as seems most probable, that the pores of the oil-bearing sands were completely filled with oil at the time the fields were first developed, then 80 to 90 per cent of the oil is left underground when the wells are abandoned. Although the evidence at hand does not permit positive statements that this proportion is being left underground, there is abundant evidence that much oil capable of being recovered remains in the sands. Complete extraction is not to be hoped for, yet there is no reason to conclude that the maximum possible recovery has been reached when the natural forces have been exhausted, and, furthermore, it has been demonstrated that it is practicable to get more oil from the sands by the processes described in this report.

It is too soon to know just how much to expect from these methods of increasing recovery, but the results have been so encouraging that

they give possibilities of new values to the properties of every producer and to the country as a whole as a new source of supply to ward off the threatened shortage. It would thus seem the part of wisdom for the individual producer and for the general public to see that the oil fields are left in condition to use these or any new or improved processes that may be discovered in the future. It should be insisted, as far as practicable, that oil wells not now profitable be abandoned in such manner that they may be reclaimed at some later date, when, as seems probable, new discoveries and improved economic conditions will make their operation profitable once more.

The problem of increasing recovery divides itself naturally into two phases—a better utilization of the natural forces in the oil-bearing formations and the employment of artificial pressures. Under present conditions probably the only generally feasible methods for recovering more oil from the formations after the natural forces have been exhausted involve the forcing of gases or liquids through the oil-bearing formation. Of the gases that might be used, only air and natural gas are practically available, and of the liquids only water.

The oldest and most extensively used of the methods previously mentioned is gas or vacuum pumping. By this method the pressures at the wells are reduced, permitting further expansion of the gas and the expulsion of more oil from the oil-bearing formations, but experience has shown that it is not adapted to all localities, and where used has only slightly increased the total recoveries from the fields. Productions of wells may be increased several times, but the benefits are temporary and the additional expenses of operation usually consume the additional gross value of the production. Were it not for the gasoline extracted from the increased volume and enriched gas, gas pumping would seldom be profitable.

Displacing the oil from the pores of the oil-bearing formations by water, commonly known as flooding, has seldom been successful, the conspicuous exception being in the Bradford field, Pennsylvania, where letting fresh water into the oil sand undoubtedly has resulted in increased recovery. As flooding practically ends all further possibilities of increasing recovery by other methods, its employment until other methods have been tried seems a shortsighted policy, even where positive results have been obtained and conditions are believed to be exceptionally favorable, as at Bradford. Elsewhere flooding has ordinarily done more harm than good, and in the occasional instances where a property has been benefited it is usually at the expense of other properties near by. Flooding has been held in general disfavor, though a few advocates have claimed that the faults lie mostly in the ways in which it is applied. In the writer's opinion natural conditions preclude its extensive success, and it is

doubtful whether as much oil is being obtained, even under the exceptionally favorable conditions at Bradford, as would be possible by other means. Certainly its use in untried fields is hazardous.

In the Smith-Dunn process, also known as the Marietta process, through its first extensive use at Marietta, Ohio, compressed air is forced into the oil-bearing formation through a few of the wells on a property, thus forcing the oil underground toward the other wells, from which it is pumped in the usual way. The process has been successfully used for nearly six years and has been applied to about 100 properties, including about 4,000 wells mostly located in the Appalachian fields. It has been successful in at least 80 per cent of the cases where used, and the records of 32 properties show an average increase of three and one-half times the production at the time the process was started. The process offers such possibilities of extended application and of further improvements that it is thought to be the most promising of the methods so far advanced for increasing recovery. Natural gas can be used similarly, but because of the scarcity and value of natural gas where such methods will be resorted to, its use will less often be practical.

As the exhaustion of a well depends principally upon the exhaustion of the gas associated with the oil, more efficient utilization of the gas in forcing the oil from the productive formation would result in increased extraction. Only limited efforts have been made to apply this principle practically, but it deserves extended investigation. The employment of the Marietta process, wherein the movements of the oil and air can be traced, has disclosed much information capable of being applied profitably to the production of oil by natural forces.

In this bulletin the writer has discussed the theoretical and the experimental data in some detail. Possibly the bulletin could have been made more useful to the industry as a whole by confining it more closely to the practical aspects of the subject. However, the author thinks that as the report is to be put before the industry when entering an entirely new phase, that of increasing the extraction of oil from old fields instead of exploiting new fields, the publication of the principles involved and the presenting of most of the information at hand were desirable. The writer realizes that the majority of practical men will not choose to go into the subject deeply, but will prefer to learn from others who have used the process; but for the ninety and nine who always follow there is the one who leads, and it is hoped that the benefits that he may derive from treating this subject fully, and the others indirectly through him, will justify the manner of treatment. It has been the endeavor to present the practical information in such a way that a reader once familiar with the report can readily find what is desired and avoid the rest.

SOME PHYSICAL PROPERTIES OF PETROLEUM AND GASES.

In the following brief discussion of certain physical properties of petroleum and gases only the factors of relatively greater importance to the recovery of oil are considered.

CHARACTER OF CRUDE OILS.

Crude oils or petroleums are mixtures of bituminous hydrocarbons, some of which are solids, some are liquids, and some are gases, the solids and gases being soluble in the liquids. A crude oil may consist of these various hydrocarbons mixed in almost any proportions, its physical properties varying accordingly. An oil may contain a quantity of the solid hydrocarbons like asphalt or paraffin and be heavy and viscous, whereas another oil may consist largely of the lighter fractions such as kerosene and gasoline and be correspondingly light and fluid.

THE SOLUBILITY OF GASES IN PETROLEUM.

The gas held in solution by the oil is an especially important factor in the recovery of oil from the formations in which it is found.

Under the same conditions of temperature and pressure a particular oil will absorb a fixed proportion of a particular gas, but this proportion or coefficient of absorption, as it is called, varies with each oil and each gas. The gas is held absorbed in the oil in the same way that soda water is charged with carbon dioxide. The proportion of gas absorbed is lessened under high temperatures, but is greatly increased under high pressures, in accordance with Henry's law of gases. Enormous quantities of gas are held in solution under the high initial pressure found in some oil wells. Some of the constituent gases are condensed at these high pressures just as in a compressor plant, and as long as high enough pressure is maintained exist as liquids dissolved in the oil. Under such conditions the gas is not absorbed as a gas but as one liquid dissolved in another, and a much greater proportion of gas can be held in solution when in liquified form than when uncondensed. Other gases (methane, ethane, and propane) are never liquified at the pressures and temperatures in oil sands penetrated by wells, but are always found as gases dissolved or absorbed in the oil.^a They constitute the so-called dry gases.

There is little available information on the solubility of natural gases in crude oils. Burrell^b has stated that actual tests showed certain California oils absorbed about 15 per cent of their volumes of the

^a Burrell, G. A., Selbert, F. M., Oberfell, G. G., The condensation of gasoline from natural gas: Bull. 88, Bureau of Mines, 1915, p. 29.

^b Letter to author.

natural gas used in Pittsburgh, Pa. The solubility of certain gases in Russian petroleum is shown by Gniewosz and Wolfies^a to be as follows:

Absorption coefficients for petroleum.

Gas.	Absorption in petroleum.		Absorption in water at 20° C. (68° F.).
	At 20° C. (68° F.).	At 10° C. (50° F.).	
Nitrogen.....per cent..	11.7	13.5	1.40
Oxygen.....do.....	20.2	27.9	2.84
Methane (marsh gas).....do.....	13.1	14.4	.....

These figures are especially interesting as showing the relative solubilities of the two chief constituent gases of air (which contains, approximately, 80 per cent nitrogen, 20 per cent oxygen) and methane, which is the principal constituent of most petroleum gases, especially during the early lives of the wells. They also show that probably the solubility of air is not much less than that of natural gas high in methane. The solubilities of the other petroleum gases, ethane, propane, and butane, are much greater, as is shown in Bulletin 42,^b Bulletin 88,^c and Technical Paper 45,^d so that the gases released at low pressures as in vacuum pumping, have far greater solubilities than methane and air.

When the pressures are not too high, considerable quantities of vapors from the lighter constituents in the oil are carried by the gases, just as water vapor is carried in the atmosphere. The carrying power of all gases is the same, provided no chemical reactions take place, and air can carry just as much gasoline vapor as can natural gas. The vapor-carrying power is decreased by high pressures, and increased by high temperatures. Under a given temperature and pressure the proportion of vapor a gas can carry will vary according to the nature of the liquid from which the vapor is derived. Burrell gives the following figures on the maximum carrying power of air for vapors of light petroleum distillates at atmospheric pressure.^e

^a Gniewosz, S., and Wolfies, A., Absorption of gases by petroleum: *Ztschr. Phys. Chem.*, Bd. 1, 1887, p. 70.

^b Burrell, G. A., and Selbert, F. M., The sampling and examination of mine gases and natural gas: *Bull. 42, Bureau of Mines*, 1913, pp. 97-98.

^c Burrell, G. A., Selbert, F. M., and Oberfell, G. G., The condensation of gasoline from natural gas: *Bull. 88, Bureau of Mines*, 1915, pp. 47-48, 69.

^d Blatchley, R. S., Waste of oil and gas in the Mid-Continent fields: *Tech. Paper 45, Bureau of Mines*, 1914, p. 44.

^e Burrell, G. A., Hazards in handling gasoline: *Tech. Paper 127, Bureau of Mines*, 1915, p. 9.

Proportions of different grades of gasoline vapor that air will carry at a temperature of 17.5° C. (63.5° F.).

Grade of gasoline.	Proportion of gasoline vapor (per cent).
Cleaner's naphtha	5.0
64° B. gasoline	11.0
69° B. gasoline	15.0
73° B. gasoline	28.0

It will be noted that the lighter the gasoline the greater the quantity of its vapor which a gas can carry.

As the pressure is reduced in a producing oil sand the absorbed gases are released from solution and the liquefied gases expand and become true gases while quantities of gasoline vapor are carried in the gases. At every reduction of pressure there is a corresponding liberation of gas and an increase in the quantity of gasoline vapors, so that the gas becomes richer and richer as the pressure is reduced, and is more desirable for the making of gasoline. In the expansion of the gases, as the pressure is reduced, an enormous amount of energy is released which is the principal force in driving the oil from the sand into the wells.

The relative proportion of oil and gas in the oil sand varies in the different fields. Often there is more gas than can be held in solution under the pressures in the oil sand, and under such circumstances the excess gas is found in separate bodies, either in a higher part of the same oil sand or in other sands overlying the oil. As the pressures generally increase with depth, usually more gas is found absorbed in the oil in the deep sands at the higher pressures, and consequently the oil contains more potential energy.

VISCOSITY, CAPILLARITY, AND ADHESION.

The physical properties of viscosity, capillarity, and adhesion of an oil have an important effect on its extraction from the oil sand, as they tend to oppose the expulsion of the oil from the sand, and must be overcome in processes for increasing the recovery of oil.

VISCOSITY.

Viscosity is defined as the internal friction of a fluid. Oils of low viscosity, like the light oils of the eastern fields, flow rapidly, whereas the thick heavy oils of California, with high viscosities, flow slowly. The viscosity of an oil is greatly decreased by heat and increased by cold. Viscosity retards the movement of the oil, but given sufficient time its effect will be overcome even by relatively low pressures.

CAPILLARITY.

Capillarity is the property that causes a liquid to be drawn into small narrow spaces even against the force of gravity. Oil rising into a lamp wick, or ink soaking into a blotter, are familiar examples. A piece of dry sandstone, or a tube full of dry sand, will draw oil up into it in the same manner, and this oil will not drain out naturally. The oil will rise rapidly at first and then slower and slower, but given sufficient time oil will rise into sand or sandstone for some distance, which, however, will seldom be more than 18 inches above the level of the fluid. Near the fluid level, the sand or sandstone will be found to be almost completely saturated, but at the top of the capillary rise the pore spaces will be only partly filled with oil. The rise

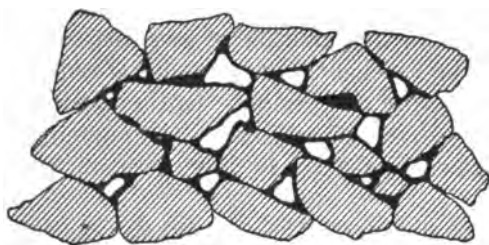


FIGURE 1.—A pile of sand grains, showing how oil is retained by capillarity and adhesion.

of the oil in the sandstone will depend upon the character of the oil (its surface tension and specific gravity), the temperature, and the fineness of the sand. The principal factor is the fineness of the pores in the sand, the oil rising much higher the finer the pore spaces are. If oil is poured through sand it will be found that some of the oil will be retained in the finer pore spaces or at the point of contact of the sand grains even though it is above the limit of capillary rise. Figure 1 illustrates this condition.

ADHESION.

The term adhesion is herein used to designate the adhering of a film of liquid to the surface of a solid such as a grain of sand. If a sheet of glass is dipped into oil, part of the oil will not drain off, but remains wetting the surface of the glass. In the same way a sand from which oil has been drained will have the surface of each grain wet with oil as well as having oil held in the finest pore spaces and in the angles of contact of the grains. The film of oil on each sand grain is very thin, but on account of the enormous aggregate surface area of all the grains in a fine-grained sand or sandstone, a considerable quantity of oil may be retained in this way. In fine uncemented sand there may be an aggregate surface of several hundred square feet in a cubic foot of packed sand.

CHARACTER OF OIL SANDS.

Sands and sandstones are by far the most important oil-producing formations. Next in importance is porous limestone, and occasionally oil is produced commercially from other porous formations such as fractured shales, or vesicular lavas.

VARIATIONS IN CHARACTER OF OIL SANDS.

An oil sand may be loose and hardly more consolidated than a beach sand, like some of those found in California and Texas, or it may be as hard and compact as building stone, such as those found in the Appalachian fields. The sand grains may be almost microscopic in size, or as large as pebbles, and they may be angular or well-rounded, of uniform size or variegated. The sand may be clean and free of silty material, mica, or natural cement, or the inter-spaces may be almost entirely occupied by such material. The porosity may be over 40 per cent or less than 10 per cent. All these differences influence the yield of oil, the quantity retained after the exhaustion of the gas, and the movements through the sands of water, oil, gas, or air. These variations are the causes of many of the problems to be solved in increasing recovery.

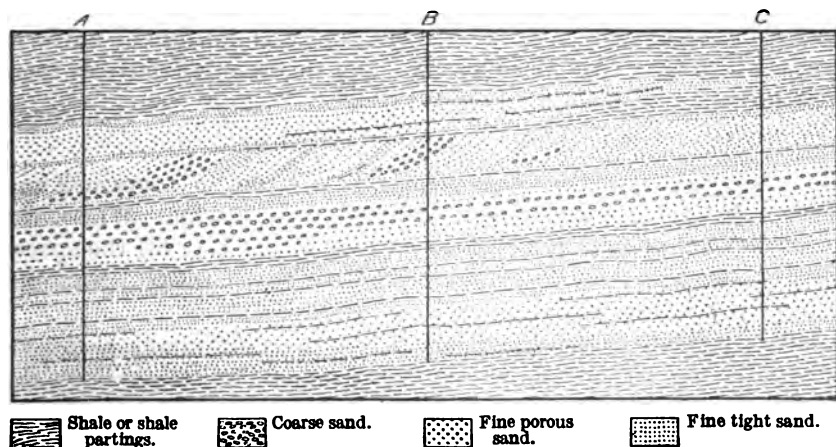


FIGURE 2.—Sketch of an oil sand showing variation in texture and bedding.

The arrangement and shapes of the pores in dolomitic limestones are not the same as in sands and sandstones; consequently they will have different effects upon the retention of oil and the movements of fluids through them. These factors may prove of much practical importance in forcing air through the rock to increase recovery, as has been shown by experience with the Smith-Dunn or Marietta process in wells in the Trenton limestone of Ohio and Indiana. The natures of the pores in sands, sandstones, and dolomitic limestones are shown in figure 1 and Plates I, A, and II.

An oil sand consists of many strata of different textures and characters, as shown in figure 2, being in reality a group of sands, frequently separated by more or less impervious layers. These breaks, or shale partings, may be so thin that they are not noticed in drilling, yet they will separate locally one layer from the other as effectively as though they were several feet thick. In all strata it is much more difficult for liquids or gases to move across the bedding from one

layer into another than along the bedding. Examinations of the outcrops of sandstones disclose these facts, while in drilling new wells or deepening old wells it is frequently found that a difference of a few inches in depth will make a tremendous difference in the capacity of a well, showing that the drill has passed through a tight part of the sand into an open part.

Similarly an oil sand or one of its layers is never of the same texture throughout the area of the field. A well at one location will find a good production, while at the next location the sand may be so tight that it will yield practically no oil, or the sand may be entirely replaced by shale. In some places the sand layers are evenly stratified; in other places the layers are cross-bedded and irregular in thickness and texture. These variations may occur within short distances and with no regularity, so that porous streaks through the formation will cause liquids or gases to travel between wells in the most erratic ways. Occasionally an oil sand is claimed to be uniform over a whole field, as at Bradford, Pa., but this is only relatively true, as important variations are found there also.

THE POROSITIES OF OIL SANDS.

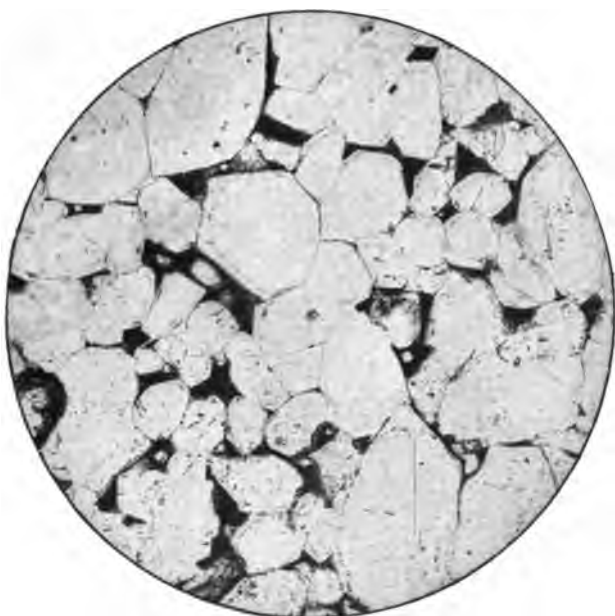
The porosity or voidage is greater in a clean, even-grained uncemented oil sand regardless of the size of the grains. Where the grains are not of uniform size, the smaller grains may fill the spaces between the larger grains and thus reduce the porosity. Silt and cementing material likewise reduce the porosity.

Porosity is one of the primary factors of productiveness, as it represents the capacity of a sand for storing oil. "Pay streaks" are the most porous or coarsest parts of the oil sand and yield oil most readily, yet it is a mistake to assume that all the oil is derived from one comparatively thin part of the sand body, for productiveness is largely a relative factor and no part of a sand is entirely lacking in porosity.

So little information was available on the porosities of sands actually producing oil that it was necessary to take data published on building stones, water supply, agriculture, and general engineering. These data are believed to represent fairly the capacities of productive sands of corresponding types because there are no general differences between productive and unproductive sands except as to contents, although the latter include some sands that, even if they were oil bearing, probably would be incapable of commercial production because their porosities would be too low or their pores too small.

King shows the average porosity of 135 samples of uncemented sands and soils to be nearly 34 per cent.* The generally accepted figure in engineering, water supply, and agricultural publications is

* King, F. H., Conditions and movements of underground waters: U. S. Geol. Survey, 19th Annual Rept., pt. 2, 1899, pp. 209-15.



A. ENLARGEMENT OF A WELL-CEMENTED SANDSTONE, SHOWING NATURE OF PORES. AFTER VAN HISE.



B. AIR-COMPRESSOR PLANT NEAR MARIETTA, OHIO, SHOWING PIPING FOR COOLING THE AIR.



ENLARGED SECTION OF TRENTON LIMESTONE, SHOWING NATURE OF PORES. AFTER ORTON.

30 to 35 per cent porosity for clean unconsolidated sands. Porosities of the uncemented oil sands of California range up to 40 per cent, and many individuals report tests showing 30 per cent or more. For California oil sands, an average porosity of 25 per cent is estimated, which is believed to be a conservative figure in view of the evidence.

Table 1 shows the porosities of about 200 sandstones of the building-stone type. Based on these data the porosities of the oil sands of the Appalachian fields are estimated to average $12\frac{1}{2}$ per cent, and for the Mid-Continent fields and Illinois, $17\frac{1}{2}$ per cent. In considering the porosities as given in the table, two facts should be noted. First, the ordinary methods of determining the porosities of sandstones generally lead to low results; and, second, building sandstones are chosen for hardness and low porosity, whereas oil sandstones are of the softest, the least compact, and the most porous varieties in each district. Undoubtedly, the average porosities, especially those computed from "ratios of absorption," are too low, and these figures include many sandstones of the types that are considered to be too tight for production in an oil field.

TABLE 1.—*The porosities of sandstones.*

Locality.	Number of tests.	Porosity.		Character of rock.
		Limits.	Average.	
Mexia, Tex. ^a.....	.....	16.60 to 34.20	25.40	Gas sand.
Petrolia, Tex. ^b.....	.....	18.50 to 27.00	22.75	Do.
Ohio c.....	6	15.87 to 17.83	16.63	Berea grit (building stone).
Missouri d.....	6	7.01 to 23.77	17.74	Building stone.
Wisconsin e.....	32	4.81 to 28.28	15.89	Do.
Washington f.....	3	10.61 to 18.00	13.17	Do.
Europe g.....	7	6.90 to 25.50	16.20	Do.

Locality.	Number of tests.	Average ratio of absorption.	Computed porosity. ^f	Character of rock.
Northeastern States ^h	25	2.66	5.98	Building stone
Ohio and Indiana ⁱ	29	5.22	11.75	Do.
Wisconsin, Minnesota, Iowa, Missouri, Michigan ^j	34	7.93	17.84	Do.
Colorado, Utah ^k	27	9.85	22.20	Do.
Other localities ^l	10	5.89	13.25	Do.
Total or average.....	134	6.50	14.60	

^a Matsen, G. C., Gas prospects south and southeast of Dallas, Tex.: Bull. 629, U. S. Geol. Survey, 1916, p. 92.

^b Shaw, E. W., Gas in the area north and west of Fort Worth, Tex.: Bull. 629, U. S. Geol. Survey, 1916, p. 38.

^c Bownocker, J. A., Building stones of Ohio: State Geol. Survey Bull. 13, 4th ser., 1915, p. 77.

^d Buckley, E. R., The quarrying industry of Missouri: Missouri Bureau of Geology and Mines, vol. 2, 2d ser., 1904, p. 317.

^e Buckley, E. R., Building and ornamental stones of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 4, econ. ser. No. 2, 1898, p. 402.

^f Shedd, S., Building and ornamental stones of Washington: State Geol. Survey Annual Rept., for 1902, vol. 2, 1903, pp. 134-138.

^g Foester, Baumaterialienkunde, vol. 1, p. 13.

^h Compiled from: Merrill, G. P., Stones for building and decoration, 1891, pp. 504-507; Hopkins, T. C., Carboniferous sandstones of western Indiana: 20th Annual Rept. Dept. Geol. and Nat. Resources of Indiana, 1895, p. 333; Buckley, E. R., Building and ornamental stones of Wisconsin, Bull. 4, econ. ser. No. 2: Wisconsin Geol. and Nat. Hist. Survey, 1898, p. 414; Smock, J. C., Building stone in New York: Bull. New York Museum, vol. 2, No. 10, September, 1890, pp. 195-395. Bain, H. F., Properties and tests of Iowa building stones: Iowa Geol. Survey Annual Rept., 1897, vol. 8, 1898, p. 410.

ⁱ Mean.
^j Porosity computed by multiplying the ratio of absorption by a factor of 24, which is justified by Buckley, E. R., The quarrying industry of Missouri: Missouri Bureau of Geology and Mines, vol. 2, 2d ser., 1904, p. 303.

White^a from tests estimated the porosities of West Virginia oil sands to range from 10 to 20 per cent. Carll^b from tests of Pennsylvania oil sands admittedly made in a crude way estimated the porosity to be from one-fifteenth to one-tenth.

EFFECTS OF TEXTURE AND CONTENTS OF A SAND ON MOVEMENTS OF LIQUIDS OR GASES.

The texture of an oil sand has an important effect on the frictional resistance to the movement of any fluid passing through it. The following table adapted from Slichter^c illustrates the effect of the relative size of the grains and porosities of sands upon the resistance to the movement of water through it:

TABLE 2.—*Relative velocities of water moving through sands of different porosities and size of grains under the same temperature and pressure.*

Kind of sand.	Diameter of grains, in fraction of an inch.	Relative velocity of water through sand having porosity of—		
		30 per cent.	34 per cent.	38 per cent.
Very fine.....	1/254	0.003282	0.004960	0.007170
Fine.....	2/254	.01315	.01983	.02965
Medium.....	4/254	.05270	.07940	.1145
Coarse.....	8/254	.2105	.3175	.4585
Fine gravel.....	50/254	8.220	12.40	17.90

The movements of oil, gas, or air will be affected just as much as that of water by the texture of the sand, a relatively slight difference in texture making a large difference in the resistance. For example, decreasing the porosity of a sand by about one-fifth increases the resistance more than two times, and if the sand grains are decreased to one-half the former size the resistance is increased four times. Between the very fine sand and the fine gravel of the same porosities there is a difference in resistance of 2,500 times. This means that air, gas, oil, or water would advance along a layer of the fine gravel about 2,500 times faster than along a layer of very fine sand.

Besides the texture of the oil sand, the character and distribution of its contents influence the movements of other fluids through it. Water moves through sands more readily than oils, especially the heavy, viscous oils, and air and gas move through far more readily than either. For these reasons a barren or partly drained part of the oil sand will offer less resistance to the movements of air, gas,

^a White, I. C., *Petroleum and natural gas*: West Virginia Geol. Survey, vol. 1A, 1904, p. 45.

^b Carll, J. F., *The geology of the oil regions of Warren, Venango, Clarion, and Butler Counties*: Second Geol. Survey of Pennsylvania, vol. 3, 1880, p. 251.

^c Slichter, C. S., *Field measurements of the rate of movement of underground waters*: Water Supply Paper 140, U. S. Geol. Survey, 1905, p. 12.

or water than the other parts, provided this effect is not counteracted by differences in texture.

Experiments showed how the movements of air or gas are influenced by the contents of a sand. A tube was packed tightly with the fine sand saturated with a California oil of 25° B. used in Table 3. Compressed air from a small laboratory compressor was forced through the tube at the full capacity of the compressor. The results are tabulated below.

Expulsion of oil from a sand by compressed air.

Total time.		Total recovery.	Pressure.
Hrs. min.	Per cent.	Pounds.	
3	-----	125	
5	50	45	
10	55	-----	
15	57		
45	64	35	
1 15	66	-----	
1 45	67.5	30	
3 15	69.5	-----	
17 15	72	28	

The first oil was expelled at 50 pounds pressure. The tube full of sand before being filled with oil showed a resistance of 18 pounds. Similar results were obtained in other experiments, the resistance to the movements of air or gas decreasing greatly with the decrease in saturation of the sand, although the volumes of free air forced through the sand at low pressures were considerably greater than at the higher pressures.

When air, gas, or water is forced into an oil sand it tends to follow the line of least resistance, governed mostly by the texture and the contents of the sand. If a part of the sand is dry, or formerly contained nothing but gas, it will be in the line of least resistance provided the texture is not too tight. If there is no gas sand, the line of least resistance will probably be through the former pay streaks or possibly the water channels. Water tends to follow along the bottom of the sand and down the dip, whereas gas or air tends to flow in the opposite direction, but in the eastern fields especially these tendencies are apt to be modified or overcome by the character and contents of the various layers of sand, which will be relatively more important. Where the top of the sand layers has been partly drained of oil it will afford a channel of less resistance, and likewise where there is less gas pressure will be a line of low resistance. Progressively with the extraction of the oil from the sand, the gas, air, or water tends to follow the parts of the formation where least oil remains.

EXPULSION OF OIL FROM A SAND.

When a well is drilled through the impervious strata capping an oil sand the pressure is released at that point and an avenue of escape for the oil and gas is afforded. The gas absorbed in the oil immediately expands and flows toward the hole, moving oil with it. As there is less frictional resistance to the movement of the gas it moves much faster than the oil, and consequently the gas is exhausted first. While the pressure is high only the dry gases absorbed in the oil are liberated, but as the pressure is reduced by the escape of gas, the wet gases, liquefied and dissolved in the oil, are released and supply energy. The composition of the gas changes as the pressure is reduced, the proportion of ethane and other higher hydrocarbon gases and vapors increasing so that the gas begins to get "wet" and becomes valuable for the extraction of gasoline by compression. There comes a time in the life of the well, provided it is not prematurely cut off, when practically all of the force of the compressed gas absorbed in the oil has been expended and gravitation is the principal remaining force. The movement of the oil then may become so slow that it does not flow into the well rapidly enough to make a profitable production, and the well is abandoned, although only a minor part of the oil may have been removed from the sand. The well is said to be exhausted, yet in reality it is not the oil, but the expulsive forces which have been exhausted.

The gas absorbed under pressure in the oil, or possibly entrapped in the pores of the sand, is the principal source of energy for expelling the oil from the sand. Occasionally the flow of oil is assisted by the pressure of free undissolved gas which may overlie the oil in the same sand body or by the movements of water. Gravitation is comparatively a weak, slow-acting force, especially where the dips of the oil sands are low and where the sand is irregular in texture and bedding, these being the commonest conditions in the oil fields of the United States. The decrease in production follows closely the decline of gas pressure at the well, and when the pressure is practically exhausted the well reaches a very low production, although much oil may remain in the sand. This shows that gravitation alone moves the oil so slowly that it has little practical effect. Experiments indicate the same fact, and there can be no doubt that the predominant expulsive force is the energy stored in the compressed gas absorbed in or associated with the oil. This is also the common opinion of others who have considered the subject for the major part of the oil recovered from a field is produced during the periods when the wells flow or are pumped so "high off bottom" that little or no oil could drain out of the sand against the column of fluid standing in the hole.

HOW OIL IS RETAINED IN THE SAND.

The expulsion of the oil from the sand is retarded and opposed by viscosity, capillarity, adhesion, and frictional resistance in the sand. It has been shown that viscosity is greatest for heavy oils and at low temperatures, and how the other factors are most important in fine sands of low porosity, especially if thinly or irregularly bedded. Frictional resistance is further increased by the sands being clogged by the deposition of waxy materials from oils of paraffin base or by the accumulation of silty materials or "floating sand" in the pores of the sands. A portion of the energy released from the expanding gas is used up in overcoming the resistance from these causes, but in addition much of the energy is wasted, owing to the escape of gas without doing work. There is a marked tendency for the gas to slip by the oil through the larger pores of the sand and through parts of the sand body offering least resistance without expending much energy in actually moving oil, this tendency increasing enormously with the removal of the oil, as shown by the experiment cited previously.

It is likely that in sands where there is the greatest opposition to the expulsion of oil—that is, in fine sands of low porosity and with heavy oils—there will be relatively less waste of energy, for the gas will not be so apt to slip through the sand without moving oil. This probably explains why tight sands and heavy oils usually give wells that maintain their productions very steadily. But the more irregular the texture and the character and proportion of contents of a sand body the greater will be the waste of energy which is essentially like the "by-passing" of air in the Smith-Dunn or Marietta process that has proved to be one of the chief difficulties to overcome in the use of compressed air.

The proportion of oil recovered from an oil sand may be said to represent a balance of the energy originally stored in the oil sand with the waste of energy and the opposition to the expulsion of the oil. This might be termed the "efficiency of expulsion," and will depend not only on the natural conditions but also upon the manner in which the producer operates his wells. While the operator can not control the original conditions of energy and resistance in the sand, he can partly control the efficiency of expulsion. As it is the energy contained in the compressed and absorbed gas rather than the oil that is exhausted, it is but logical to judge the efficiency of a producing method largely by the relative quantities of gas produced with each barrel of oil. If by a change in method the producer lessens the proportion of gas with each barrel of oil, he should increase the total recovery of oil correspondingly, even if the rate of production is temporarily reduced somewhat.

Of the oil retained in the sand after a well has reached economic exhaustion under the customary production methods, part is retained so tightly by capillarity in the finest pores as well as by adhesion to the surfaces of the sand grains (fig. 1) that its removal seems to be possible only by using heat or solution. How much oil may thus be retained is shown by Table 3, although other experiments have disclosed that a somewhat greater proportion, especially of the heavier oils and in the finer sands, may be removed by the continued passage of compressed air or gas through the sand. This quantity retained appears to mark the ultimate limits of recovery of any of the methods discussed in this paper, but between this probably irrecoverable minimum and what ordinarily has been left in the oil sands there is a vast quantity of oil that can be recovered by the agencies discussed. This includes oil that in time would drain out naturally, and oil that is trapped in the sands by water or pocketed in irregularities in the sand body. Some other forces than gravity or the weak gas pressure remaining in the sand are required to expel such oil at a commercial rate.

Probably the bulk of the oil retained in the sand is oil that theoretically can be recovered. How viscosity and frictional resistance retard the movements of the oil has been discussed. After the sand has been partly drained the movement of oil is so retarded from these causes that it becomes exceedingly slow even under the most favorable conditions. Usually the oil sand is split into many layers and lies nearly flat so it readily may be understood how much oil might remain in the sand and yet the well not yield commercial production. A measure of the force of gravitation under these conditions may be gained from considering the results from using vacuum pumps on wells that are nearly exhausted. Reducing the pressure only 10 to 12 pounds will often double or treble the production for the time being.

It has been shown how capillarity holds the oil in the sand, more oil being held at the base and less toward the top. The proportion retained will be largest in the finest grained sands, and the proportion will be greatly increased where the sands are thinly and irregularly bedded. Every impervious or semi-impervious streak of shale or other material, no matter how thin, will act as a base for capillarity, although if the beds dip steeply much of the oil will drain down the slope by gravity. Likewise streaks of coarser or more porous sands will cause the retention of more oil in the finer parts of the sand, as disclosed by the experiment cited in another paragraph. Where the sand is nearly level and is split by many shale partings, or tight or coarser streaks, a large proportion of the oil may be held by capillarity.

The proportion of oil that may be retained in this way is indicated by Table 3, which gives the results of a few laboratory experiments. In these tests glass tubes $1\frac{1}{2}$ inches in diameter and 20 inches in length were tamped full of sand, set upright, and the sand saturated by forcing oil up from the bottom. They were then drained at a temperature of 70° F. through a small glass tube at the bottom. The remaining oil was measured after drainage had become extremely slow and had practically ceased, no further loss in weight being detected in several days. If the draining had been continued over a long period possibly a little more oil would have been removed, but the experiments were carried on until a rate had been reached far beyond what was thought to represent the practical limits in oil production. The experiments were not carried to the greatest accuracy but are believed to contain no material errors. The full range of conditions found in the oil fields was not covered, and both the upper and lower limits may be exceeded, but these figures illustrate the possibilities of oil being retained in this way. The conditions of the experiments, a homogeneous mass of clean sand in an upright tube, are far more favorable for draining in almost every particular than are those ordinarily found in oil sands and suggest how much oil may be retained when gravity is the sole force for expelling the oil.

How tightly this oil is retained was shown by letting fresh water flow through the tubes of drained sand from the bottom to the top at a temperature of 70° F., for from only one tube was there even a color of oil on the water after it had passed through.

The sands experimented with were a coarse sand, having well-rounded grains of uniform size, average diameter about six two-hundred-and-fifty-fourths inch, and a porosity about 37 per cent, and a finer sand, having angular grains of irregular size, about three two-hundred-and-fifty-fourths inch average diameter, and an average porosity of 38.5 per cent.

TABLE 3.—Quantities of oil retained in drained sands.

Oil.	Sand.	Time drained, days.	Oil retained, percentage of capacity of sand.
Bradford crude, gravity 41.2° B. (0.818).....	Coarse.....	26	15.0
Do.....	Fine.....	26	21.0
California crude, gravity 25.1° B. (0.903).....	Coarse.....	42	24.0
Do.....	Fine.....	43	42.0
California crude, gravity 14° B. (0.972).....	Coarse.....	73	30.5
Do.....	Fine.....	73	53.0

To determine how alternating layers of coarse and of fine sand affect the amount of oil retained, a tube was packed with alternating

layers of such sands, saturated with oil and then allowed to drain until no further loss of weight could be detected during a period of several days. The results were compared with those obtained by using similar tubes in which only one of the sands was packed. In the fine sand alone, 21 per cent of oil was retained; with the coarse sand alone, 18 per cent; whereas with the two sands in alternating layers, 35 per cent of the oil in the tube did not drain out. No barriers were interposed between the layers in the two kinds of sand, yet much oil remained concentrated in the layers of finer sand, its superior capillary power not permitting the coarse sand below to withdraw the oil.

Other experiments indicated that the ultimate recoveries by water displacement were no greater and, indeed, appeared to be somewhat smaller than by natural drainage even under the favorable laboratory conditions. In these experiments water was allowed to rise through the tubes from the bottom to the top under various conditions of sand, oil, and pressure. Always a considerable portion of the oil displaced and flushed from the sand was accompanied by so much water that its recovery would not be feasible in the field. When the experimental conditions more nearly resembled field conditions the oil displaced, unaccompanied by water, was much less, so that the oil ultimately retained in the sand became greater. This was particularly true when the sand had been partly drained before letting the water rise through it, the water showing a marked tendency to bypass and trap the oil.

By forcing compressed air or gas through the tubes greater recoveries were obtained than by natural drainage or by water displacement. With the same oils and the same fine sand as in Table 3, only 17½ per cent of the 41.2° B. Bradford oil and 28 per cent of the 25.1° B. California oil were retained, the relative recovery being greater with the heavier oil. After all the oil possible had been removed by the air or gas, the passage of water even under 50 pounds pressure failed to remove as much as an iridescent film of oil from the sand.

At this time no general statements in regard to the efficiency of the recovery of oil under the various natural conditions can be made, except that it is generally considered to be greater in the deeper sands because pressures are generally greater; however, the smaller cost of producing from shallow wells allows them to be pumped to smaller productions, which partly compensates for the greater energy stored in the deeper sands. In small quantities salt water is generally considered to result in greater recovery in the eastern fields in sandstones producing paraffin oils, but in larger quantities it increases the cost of production and cuts short the life of the well. Where a sand is flooded with water, as in a "water drive," the water is almost cer-

tain to trap a large part of the oil. The spacing of wells also affects the recovery of oil from the sand, as well as the method of operating them. Commercial conditions are important factors, for if it were profitable to pump the well down to one-tenth of a barrel a day, as is done in some Pennsylvania fields, obviously there would be less oil left in the sand than if 10 barrels daily were the economic minimum, as for some California wells. The life of a well is terminated at the point where production ceases to be profitable, and not by the complete exhaustion of the oil.

PROPORTION OF OIL LEFT UNDERGROUND.

While it is obvious that both the proportion retained and the additional oil possible of recovery will vary under the diverse conditions in the fields of the United States, yet in the following paragraphs reasons are advanced for thinking that the usual methods of production are leaving by far the larger part of the oil underground and that a considerable part of this oil seems possible of recovery.

What percentage of the oil is retained in a sand after the wells are abandoned and how much of the retained oil is capable of commercial extraction are matters of varying opinion. Reliable estimates of the quantities of oil remaining in a field after the wells have been considered exhausted would be highly desirable, for they would demonstrate the incompleteness of the usual production methods and how much effort was warranted in devising and applying ways to increase recovery. There is much evidence showing that immense quantities of oil capable of being extracted remains underground, and probably more oil is left in the sands than is brought to the surface.

Opinions on the amount of oil left underground have ranged from 25 to 90 per cent, the commonest estimates being about 50 per cent. Precise data have never been submitted with any of the estimates, they being frankly generalities based on the judgments and experiences of the estimators. Some of the estimates are as follows: White,^a 25 per cent for the oil sands of West Virginia; Arnold and Garfias,^b 40 to 60 per cent for the oil sands of California; Ashburner,^c 90 per cent for the oil sands of Pennsylvania; Dunn,^d 25 to 85 per cent; Naramore,^e 90 per cent; Washburne,^f 36 to 60 per cent.

^a White, I. C., *Petroleum and natural gas: West Virginia Geol. Survey*, vol. 1, 1904, p. 46.

^b Arnold, R., and Garfias, V. R., *Methods of oil recovery in California: Tech. Paper 70, Bureau of Mines*, 1914, p. 6.

^c Ashburner, C. A., *Petroleum and natural gas in New York: Trans. Am. Inst. Min. Eng.*, vol. 16, 1887-88, p. 915.

^d Dunn, I. L., *Statement before Corporation Commission of Oklahoma*, 1915.

^e Naramore, Chester, *Personal communication*.

^f Washburne, C. W., *The estimation of oil reserves: Bull. 98, Am. Inst. Min. Eng.*, February, 1915, pp. 469-471.

The estimate of Ashburner, made in 1887, is especially interesting: Ashburner says:

From my own estimates, I have determined that the oil-producing sand in the Venango district up to the present time has produced an average of only 900,000 barrels of oil per square mile. It is impossible to determine the absolute thickness of the reservoir sand over any definite area, even as small as that of 1 square mile. There are so many variable factors which enter into the problem that it is difficult to arrive at any fair conclusion on the question of relative porosity. From estimates which I have made of the producing capacity of the oil and gas sands of the different Pennsylvania and New York districts, I believe that the amount of oil which will be ultimately retained by capillary attraction in the pores of the sand beds will range from eight to nine times as much as the total amount of oil which it will be possible to extract from these sands through wells.

There is much positive evidence that recoveries are far from complete. The wells are seldom entirely exhausted when abandoned, whereas wells that have been abandoned for many years have been rejuvenated and made productive again in some eastern fields by the Smith-Dunn or Marietta process and at Bradford, Pa., by water flooding. New wells drilled among old wells show that the oil is not exhausted, and in some of the older Appalachian fields a second or even a third crop of wells has been drilled. The results with the compressed-air process described herein and those with flooding at Bradford have demonstrated that much oil capable of commercial extraction remains in the fields after they have been virtually exhausted by the usual production methods. These processes, however, have not been used long enough to show just how great the increased recovery will be.

In subsequent paragraphs it is shown that the productions of the fields in the United States have been only a fraction of the capacities of the oil sands conservatively estimated. If these figures could be accepted without reservation to apply to the proportion of oil left unrecovered, the author would estimate that only 10 to 20 per cent of the oil ordinarily is extracted.

It has been shown that the commercial exhaustion of a well follows the exhaustion of the gas, and is not necessarily due to the exhaustion of the oil in the productive formation. Data derived from experiments and from facts observed in the oil fields show that much oil may be retained in the sand after the gas has been exhausted, and only the comparatively weak force of gravity remains to expel the oil. Considering these facts and bearing in mind that the decline of an oil well is coincident with the exhaustion of the gas pressure, it seems not improbable that only a minor part of the oil is brought to the surface. It is known that the gas escapes from the sand much faster than the oil and that the quantity of gas usually produced with a barrel of oil is much greater than could have been absorbed in

that quantity of oil under the pressures and other conditions existing underground even when the oil sand was not connected with the gas sand.

It may be possible, by observing the quantity of gas produced with the oil during a period in the life of the wells, and the decreases in gas pressure and the changes in composition of the gas during this period, to determine from the laws of the physical relations of gases and liquids whether all or what proportion of the gas has been held in solution, and to estimate the quantity of oil underground in which it had been absorbed. So far as known to the writer, such a method has never been tried in the oil fields, but it is based upon well-known scientific laws, and it is suggested that if practically applied it might give the results desired without having to estimate the porosity, thickness, or area of the oil sand.

As shown previously by experimental data, the volume of air or of a gas necessary to expel an additional portion of the oil remaining in the sand increases tremendously with the progressive extraction of the oil from the sand. For example, it was found in certain other experiments with the same Bradford oil and fine sand, shown in Table 3, that to expel an additional per cent of the oil after some 50 per cent had already been removed, required hundreds of times greater volume of free gas (artificial gas used in San Francisco, Cal.) at the same pressure than when the sand was only 30 per cent drained, and thousands of times greater than when only 10 or 20 per cent drained. The efficiency of expulsion decreases enormously with each decrease in degree of saturation, so that the greatest actual as well as relative recovery would be obtained where the sands were fully or nearly saturated, even if more gas could be stored in the sands when less completely filled with oil. The experiments indicate that it would hardly be possible to store in the oil sands gas enough under sufficient pressure, within the limits found in the oil fields, to expel any high percentage of the oil, and that the smaller the degree of saturation the smaller the percentage of the contained oil that would be expelled. Compared with these experimental conditions the conditions in the oil sands are far less favorable; the thickness and irregularity of the sand body, as well as the greater distances the oil and gas would have to travel to the wells, all make for greater waste of the expulsive force and a general decrease in efficiency. The observed fact that much more gas accompanies the production of a barrel of oil than could be held in solution under the original well pressures is in harmony with these experimental results, and indicates that the expulsive force contained in several barrels of oil is required to expel one from the sand. For these reasons the theory of low original saturation of the oil sands sometimes advanced to explain low recoveries seems very improbable, likewise high recoveries are

not to be expected, and the estimate of 80 to 90 per cent of the oil left underground does not seem incredible.

Obviously much of the oil will never be capable of commercial extraction, but what this minimum unextractable proportion may be no one can tell until further efforts have been made to increase recovery. It has been customary for the operators to accept the natural decline and commercial exhaustion of their wells without question or further efforts to see whether it was the oil itself or the forces in the sand that were exhausted and there is no reason to believe that both are exhausted at the same time. The truth seems to be that the natural forces in the oil sands are sufficient to expel only a small portion of the oil and that much of the remaining oil is capable of recovery if new forces are applied.

CAPACITIES OF OIL SANDS.

From the evidence previously submitted the following figures on the porosities of oil sands are believed to be reasonable. The porosities of oil sands are much greater than the uninformed would suspect from a casual inspection of specimens, whereas the usual ways of testing the porosity lead to underestimates. There is little published information on the porosities of sands actually productive of gas or oil, but there is no reason to believe that they are less than for other sands and sandstones. Indeed, as pointed out previously, the porosities of the oil-producing sandstones of the Mid-Continent and eastern fields must be greater than the figures on the building sandstones indicate. In any event, the recovery of gas shows that the estimated capacities of the oil sands, as given in the following table, can not be in gross error.

Estimated average capacities of oil sands.

	Estimated average porosity, per cent.	Capacity per acre-foot, barrels.
Appalachian field.....	12½	970
Illinois and Mid-Continent fields.....	17½	1,358
California fields.....	25	1,940

ACTUAL RECOVERY FROM OIL AND GAS SANDS.

According to the United States Geological Survey,* 3,335,457,140 barrels of oil have been marketed from 329,186 oil wells in the United States up to the beginning of 1915. During 1914, 265,762,535 barrels were marketed from 179,129 oil wells. It is estimated that the average well drained about 6 acres of oil land, the total area

* Northrup, J. D., *Petroleum: Mineral Resources U. S. for 1914*, U. S. Geol. Survey, 1915, p. 889.

being about 2,000,000 acres. The future production for the wells producing in 1914 is estimated to be not more than 1,400,000,000 barrels, making a total production of approximately 4,700,000,000 barrels, or approximately 2,350 barrels per acre, which is hardly enough to saturate an oil sand 2 feet thick of average porosity.

Statistics by the United States Geological Survey^a show that 591,866,733,000 cubic feet of natural gas was produced and used in the United States in 1914, which does not include the enormous wastage. The average pressure being approximately 250 pounds at the well, the space occupied would be equivalent to some 5,850,000,000 barrels of oil, which is nearly double the total oil production and is twenty-two times the oil production for 1914. If 40 acres be allowed for each gas well producing in 1914, the area of gas-producing sands was about 1,400,000 acres, which is not as much as the total oil-producing sand. This gas was produced from sands which yield oil in the same districts, and there is no evidence that their capacities are greater than for oil sands. Similar comparisons for former years show even greater discrepancies between the spaces occupied by the oil and gas.

Day,^b in 1907, estimated the recovery from the Appalachian fields to have been less than 800 barrels per acre. On this basis the total recovery will not exceed 1,000 barrels per acre, or only enough to saturate an oil sand 1 foot thick with a porosity of 12½ per cent. White^c has estimated the average thickness of the pay streaks alone to be 5 feet in West Virginia. This is undoubtedly a conservative estimate when applied to the whole Appalachian fields.

From available records the production of the Bradford field,^d in Pennsylvania, has been about 230,000,000 barrels. The area of the field is said to be approximately 85,000 acres.^e The average well production is now but a small fraction of a barrel daily, so that the field may be considered practically exhausted, yet the total production has approximated only 2,700 barrels per acre, or not enough to saturate 3 feet of sand, although the sand is reported to average 45 feet thick and to be oil bearing and comparatively uniform throughout.

The marketed oil production of Illinois to 1915 has been 232,326,616 barrels from 19,808 wells. In 1914 the marketed production was

^a Northrup, J. D., *Natural gas: Mineral Resources U. S. for 1914*, U. S. Geol. Survey, 1915, p. 749.

^b Day, D. T., *Petroleum resources of the United States: Bull. 394*, U. S. Geol. Survey, 1909, p. 34.

^c White, I. C., *Petroleum and natural gas: West Virginia Geol. Survey, Vol. I*, 1904, p. 46.

^d Compiled from statistics of Second Geographical Survey of Pennsylvania, vol. 10; U. S. Census Report; and annual volumes of Mineral Resources of United States, U. S. Geol. Survey. Productions for 1885-1887, 1890, 1907-1914 are estimated.

^e Ashburner, C. A., *Second U. S. Census Report*, p. 432.

21,919,749 barrels from 14,800 wells, whose future production is estimated to be about 100,000,000 barrels, or a total of about 330,000,000 barrels. Assuming a drainage area of about 6 acres per well, each acre will contribute about 2,750 barrels, which would saturate an oil sand 2 feet thick of $17\frac{1}{2}$ per cent porosity, yet the thickness of the "pay streaks" in the average well of Illinois has been estimated to approximate 25 feet.^a

The total oil marketed from Oklahoma up to 1915 has been about 462,000,000 barrels, to which 38,875 wells have contributed. The marketed production in 1914 was 73,631,724 barrels from 27,794 wells, and the future production can be reasonably estimated not to exceed 300,000,000 barrels, a total of 762,000,000 barrels. From a record of over 6,000 wells on the lands of restricted Indians^b it is found that there is on the average one well to each 5.7 acres, at which figure the total producing acreage in Oklahoma is not over 225,000 acres, and the production per acre will approximate 3,400 barrels, which would not saturate 3 feet of sand of the estimated porosity, although the average thickness of the oil sands in Oklahoma is many times greater.

A large gas company operating in northeastern Oklahoma estimates from its experience that the marketed production from an average gas well in that district is about 300,000,000 cubic feet.^c This does not include the enormous wastage or the gas left underground. The average original pressure in the gas fields in this part of the State would be about 600 pounds, or, roughly, 40 atmospheres, and there would be an average of one gas well to 40 acres of gas land. From these figures it is calculated that the gas must have come from sands which average 24 feet in thickness and would contain 33,500 barrels per acre, or ten times the thickness of sand indicated by the recovery of oil. The gas is produced from sands that are oil bearing near by.

McLaughlin^d states that the recovery from the Kern River field, in California, has been approximately 26,000 barrels per acre to 1915. As the field has been producing for 14 years, and is nearly drilled up, an optimistic estimate of the future production would make the total recovery not more than 40,000 barrels per acre, or enough to saturate about 20 feet of sand, whereas a thickness of 200 to 300 feet is reported in that field. McLaughlin also reports actual recoveries from a number of properties in the Midway and Coalinga

^a Day, D. T., Petroleum resources of the United States: Bull. 394, U. S. Geol. Survey, 1909, p. 34.

^b Second annual report United States oil and gas inspector for the Five Civilized Tribes, 1915.

^c Personal communication from A. J. Deischer, of Bartlesville, Okla.

^d McLaughlin, R. P., Petroleum industry of California: Bull. 69, State Mining Bureau, 1914, p. 204.

fields, California, from which the following tabulation has been made:^a

Recoveries from the Coalinga and Midway fields, California.

[Adapted from data by R. P. McLaughlin.]

	Coalinga.	Midway.
Number of properties	13	18
Average thicknesses of oil sands, feet.....	96	90
Average production per acre, barrels.....	22, 012	13, 579
Average age of well, years.....	6	4
Average production per acre-foot, barrels.....	222. 5	151
Average recovery, ^b per cent.....	11. 5	7. 8
Minimum production per acre-foot, barrels.....	26. 5	51
Minimum recovery, ^b per cent.....	1. 4	2. 6
Maximum production per acre-foot, barrels.....	838	742
Maximum recovery, ^b per cent.....	43. 3	38. 2

These properties are still producing but have yielded at least two-thirds of their total production. The figures show that the recovery will average not more than 15 to 20 per cent of the assumed porosity of 25 per cent. The difference in individual yields is noteworthy and can not be explained by relative skill in operating the wells but is due mostly to natural conditions. Undoubtedly there are considerable variations in the porosities of the sands and also errors in estimating their thicknesses and the areas of drainage, but these facts can not fully reconcile the extremes of recovery of 1.4 per cent and 43.3 per cent shown in the table. Occasionally the recovery from individual wells or small properties is very high, and at times it is difficult to explain how so much oil could be obtained from these properties, but almost invariably such high recovery is from the first wells drilled in a field of high pressure, and undoubtedly a much larger area has contributed to the yield than has been figured. These high extremes have led many engineers to overestimate the future recoveries from oil fields, but when the entire field is considered it will be found that the average recoveries are low and that the high recoveries are abnormal and very rare.

Although the estimates given are only approximate, there can be no reason for doubting, after fair deductions have been made for errors and overestimates, that ordinarily the oil produced represents only a small part of the capacity of the sand. The differences between recovery and capacity are so large that few possible sources of error or other factors could reconcile them. The estimated capacities of the oil sands are within reasonable accord with the recoveries of gas from continuations of the same sand beds in the same districts, and there are no reasons known why their average porosities and

^a McLaughlin, R. P., work cited.

^b Twenty-five per cent porosity and complete saturation assumed.

thicknesses should be less where oil bearing. The quantities of gas produced with the oil, where the gas is known to come only from oil-producing sands, indicate that the capacity of the oil sands is much greater than the volume of oil recovered, and hence either the recovery is very small or a large part of the pore space is occupied by free undissolved gas mechanically entangled with the oil. In the writer's opinion a solution of this problem would determine whether the recoveries made actually approximate only a fifth or tenth part of the oil in the sand. The experiments show that an excess of gas is to be expected with the oil even if the sand is fully saturated and that with partial saturation an even larger percentage of the oil contained in the sand can be expected to be left underground. In any event the efforts so far made to increase recovery show that enough more oil could be brought to the surface by applying additional pressure in the sand to make such efforts worth while.

USE OF GAS PUMPS FOR INCREASING PRODUCTION OF OIL WELLS.

Vacuum or gas pumps, according to Carll,^a were first employed in the old Triumph pool, Pennsylvania, in 1869. Their use gradually increased in the Appalachian fields, and during the past 10 years they have been employed extensively throughout the Mid-Continent fields and the fields east of the Mississippi River.

The effect of the gas pump is twofold. It increases the yield of oil and the quantity and richness of the gas. Its effect on the gas production has had a marked influence on the condensation of gasoline from casing-head gas by compression, and many gasoline plants would not be in use to-day except for the gas pumps. On the other hand, gas pumps would not be used so extensively were it not for the natural-gas gasoline plants, for experience has shown that gas pumps are seldom profitable from the increase of oil production alone. The benefits of increasing the oil production are short lived, and are accompanied by much extra trouble and expense.

It has been shown that reduction of pressure in an oil sand releases more gas from solution and permits greater expansion of the gas. Samples of oil several years old will froth and become lively when subjected to a few pounds of negative pressure showing how gas and vapors are liberated at reduced pressures. Consequently reducing the pressure at the well below atmospheric by a gas pump provides additional expulsive forces in the sand not available before. The theoretical vacuum limit of gas pumps is -14.7 pounds per square inch at sea level, and less at higher elevations. It has been claimed that a vacuum of -13 pounds has been reached in actual practice. Gas pumps are placed on wells after the pro-

^a Carll, J. F., Seventh report on the oil and gas fields of western Pennsylvania: Second Geol. Survey of Pennsylvania, 1890, pp. 12-13.

duction has declined to a very small figure and the gas has nearly reached atmospheric pressure; hence the reduction of pressure ordinarily effected by the gas pump is not more than 15 or 20 pounds per square inch. As the effectiveness of the gas pump depends principally upon the gases released in the oil sand by the reduced pressure, the limit of its usefulness is reached when these gases are exhausted from the sand, unless air or natural gas is allowed to enter the sand, and is sucked through by the gas pump. Results of sucking air through the sand should be practically the same as forcing air through the sand at positive pressures of not more than 13 pounds. It is obvious that when the natural gas accompanying the oil has been exhausted the practical limit of efficiency of the gas pumps has been reached so far as increasing the production of oil is concerned.

Gas pumps are not employed until the wells have reached low pressures and small productions. Usually the production of oil is increased, sometimes it is doubled or trebled, but this favorable effect seldom lasts long, and in a few years the production drops to or below the former level. Figures 11, 12, and 13 (see pp. 68-69) show the effects of the use of gas pumps on the productions from certain properties, and also how inadequate the method is for extracting all the oil in the sand. It is not claimed, however, that these properties represent a fair average for the benefits derived from gas pumping.

Gas pumping considerably increases the cost of producing oil, and this increase is not often compensated by the extra profits derived from the increase of oil production alone. Considerable equipment must be invested in and attended to, as the method requires a gas engine, suction pump with housing and accessories, and suction lines extended to every well, while each well must be packed tightly. The suction in the well often causes the walls to cave, or increases the amount of floating sand and silt coming in with the oil so that casings must be pulled oftener, and the wear on pumping apparatus is much greater. While the well is being "pulled," the air rushes into the sand and drives the oil away from the hole, and there being no gas pressure in the sand to force the oil back it may be many days after the well is put back on the suction line before the oil is brought back to the hole. During this time the well is a nonproducer so that although the daily yield may be increased during the time the wells are actually pumped, the production over a longer period is likely to prove disappointing. This loss of time, and the expense of "pulling the wells" and of keeping up the plant, is apt to more than counterbalance benefits derived from the increase in production, as it is temporary and seldom lasts more than 3 or 4 years. Once the property has been gas pumped, however, experience shows that usually pumping at negative pressures can not be discontinued, because the air

rushing into the sand drives the oil away from the well and makes it almost impossible to obtain profitable production again by ordinary methods, hence gas pumping must be continued long after the benefits from it have ceased. The writer believes, however, this evil effect can be lessened by letting the air into the sand very gradually and thus reducing the force of the intruding air.

After most of the gas in the oil sand has been removed and the pressure reduced below atmospheric, gravitational drainage and possibly water flushing are the only motive forces left to move the oil from the sand. How little effect gravity alone has upon the movement of the oil is shown by the fact that the production practically ceases when gas pumping is stopped after the pressure in the well has been reduced below atmospheric. The oil does not flow into the wells when the flow of the small volume of gas caused by the suction ceases. Carll^{*} in speaking of conditions in the Triumph pool, Pennsylvania, after gas pumping had been continued until there were negative pressures of -12 pounds in the oil sand, says:

New wells are occasionally drilled on this exhausted belt, and it invariably happens that when this oil sand is pierced a current of air commences to whistle down the hole, nor can any oil be obtained till the well mouth is closed and a gas pump put in operation. After a few days' testing, oil begins to appear and the production frequently runs up to 15 to 20 barrels per day. Then, as the slight excess of fluid in the immediate vicinity of the hole drains, and an equilibrium is established, the output gradually shrinks to the level of the old wells in the pool.

Although the use of gas pumps is seldom justified by the increase of oil production, it frequently becomes profitable, as formerly stated, through the gasoline derived from the gas. Probably the majority of casing-head gasoline compressor plants in the Mid-Continent fields and the fields east of the Mississippi River use gas from gas-pumped wells, and this is often extraordinarily rich in gasoline vapors. To a considerable extent the casing-head gasoline production, which has reached enormous proportions in recent years, is dependent upon gas pumping. The recent high prices of gasoline have greatly stimulated the installation of gas pumps, and made the process profitable where heretofore it was not. The process is considered to be especially profitable in some of the Oklahoma fields.

The use of gas pumps has in the past been generally condemned by producers upon the ground that it seldom pays, but inquiries have failed to disclose opinions that the process injures the sand. In the writer's opinion it may possibly aggravate water troubles by lowering the pressure in the sand, but otherwise he has no facts showing it to be seriously injurious.

^{*} Carll, J. F., Seventh report on the oil and gas fields of western Pennsylvania: Second Geol. Survey of Pennsylvania, 1890, pp. 12-13.

One motive for installing gas pumps has been to draw production from adjoining properties. As the pressures are lower at wells being gas pumped, the gas in the district tends to flow toward those wells, and the areas drained by the wells are correspondingly increased. If an operator can install gas pumps before his neighbors, he gains a certain advantage, and they consider that they must install pumps on their own wells to overcome this advantage. This fact is one of the chief objections that have been raised against its use. Once gas pumping is started in a field, its use is apt to extend to all other properties.

It is believed the effect of gas pumping upon oil production of neighboring properties has probably been overestimated, though where the gas is the consideration the effect is of undoubted importance.

The effects of gas pumping may be summarized as follows: It temporarily increases production, but likewise increases expenses and operating troubles correspondingly, so that it seldom pays except where profits are derived from an increase in the volume and richness of the gas. The method hastens the recovery of the oil, but the total recovery is only slightly more than that by ordinary pumping methods.

SMITH-DUNN OR MARIETTA COMPRESSED-AIR PROCESS.

HISTORY OF PROCESS.^a

The present successful practice of stimulating the production from oil wells by forcing air through the oil sand was started on the Wood farm of the Cumberland Oil Co., near Chesterhill, Ohio, by I. L. Dunn, in August, 1911. However valid the claims of others for priority in idea and application may be, the fact remains that the now extensive use of this method can be traced back to this first successful demonstration. With the aid of Orton C. Dunn and Harvey E. Smith, the details of practical operation were worked out and demonstrated to other oil producers. Because Messrs. Smith and Dunn have been credited with bringing the method into successful public use, the process has become known as the Smith-Dunn process, though it is also called the Marietta process because of its first extensive use near Marietta, Ohio.

Mr. I. L. Dunn states that his idea originated when operating in the Macksburg pool, Ohio, in 1903, when gas at a pressure of 45 pounds was forced into an oil well producing from the 500-foot sand. After 10 days the gas pressure was released and the well began to pump much oil, which continued till the gas had worked out again. In 1911 the experiments on the Wood farm were started. About 150,000 cubic feet of free air was compressed and forced into one well daily, at a pressure of 40 pounds, and within a week the production of the surrounding wells had increased, after which the use of compressed air was extended to other parts of the property. The Wood farm is located in the "Chesterhill streak," production being obtained from the First Cow Run sand at depths averaging about 450 feet. This property had been drilled in 1898 and had been gas pumped for several years. At the time the experiment was started, the production had dropped to an average of 7 gallons per well daily. The oil is of paraffin base, has a gravity of more than 40° B., and the sand is coarse and pebbly. The effect of the process on this property is shown in figure 11 (see p. 68).

The process is known to have been employed on over 90 properties, of which at least 80 per cent have been successful. Nearly all of these properties are located in the Appalachian fields in the south-

^a The principle of increasing production by forcing air or any other gas through the oil sand, and many details of operation, are covered by U. S. patents controlled mostly by I. L. Dunn, of Marietta, Ohio, and others. See *Oil and Gas Journal*, vol. 15, No. 4, June 29, 1916, p. 84.

eastern parts of Ohio and the northwestern parts of West Virginia. Probably 4,000 wells have been affected by the process, and its use is extending rapidly, being retarded principally by the difficulty in obtaining machinery under the present abnormal conditions. Few of the plants are more than three years old, and probably half the plants were installed during the past year (1916). It was not until recently that the producers in the district became fully awakened as to what was being accomplished, and as to how much oil still remains underground. The recent expansion in the use of this process is sufficient warrant of its practicability and success.

PRINCIPLES OF PROCESS.

The essential principle of the Smith-Dunn or Marietta process is to replace the natural gas, which originally accompanied the oil and was the principal agent in forcing the oil into the wells but has been exhausted, with compressed air. The air is forced into the sand under pressures varying from 40 to 300 pounds through some of the wells on the property, which are called "air wells," the oil being pumped from the other wells in the usual way. Any gas which does not combine with the oil chemically under the conditions existing underground could be used, but of these gases only air and natural gas are practically available. On the old, nearly exhausted properties where the process has been employed natural gas is seldom available, or only at excessive costs, and it is seldom practicable to use anything but air.

PROCEDURE IN INSTALLING PROCESS.

EQUIPMENT REQUIRED.

The extra equipment necessary for using the process over that commonly used on any producing oil lease consists of an air-compressor plant, a system of piping for conveying the compressed air to the air wells, and the preparation of certain wells for taking air.

The air compressor can be of any efficient type, and is usually driven by a gas engine, because gas is in nearly every instance the cheapest and most available fuel. However, any other type of engine can be employed. The tendency has been toward using direct-driven types because of greater efficiency and compactness.

The compressors in use vary in size from 20 to 100 horsepower. It is considered advisable to restrict the size of the units to 100 horsepower, and where more power is needed to install additional units. Where the air is compressed to a pressure of more than 100 pounds, two-stage compressors are generally used. Some operators recommend that 80 pounds is the better maximum for single-stage compressors. Information on compressors used at 42 properties, with various other data, are presented in Table 4.

TABLE 4.—Conditions on 42 properties using the Smith-Dunn or Marietta process.

Number of property.	Name of oil sand.	Texture of sand.	Approximate average depth of wells, feet.	Number of wells on property.		Age of wells, years.	Previously gas pumped.	Rated horsepower of compressor.	Rated horsepower per well.	Approximate air pressure used, pounds per square inch.
				All wells.	Air wells.					
1	First Cow Run.	Coarse.	450	108	28	18	Yes.	90	0.83	45
2	do.	do.	700	58	19	18	Yes.	150	2.6	70
3	do.	do.	400	27	7	20	Yes.	40	1.5	45
4	do.	do.	80-120	100	35	20-55	Yes.	150	1.5	40
5	Macksburg 500	Medium.	500-700	19	6	20-55	No.	35	1.8	110
6	First Cow Run.	do.	600	32	9	16	Yes.	40	1.25	50
7	do.	Coarse.	80-400	140	40	20-55	Yes.	185	1.3	55
8	Rosenberry.	Coarse and fine (or stray sand).	1,300	91	21	24	Yes.	180	2.0	70
9	First Cow Run.	Medium.	250	16	5	11-13	Yes.	20	1.25	45
10	do.	do.	700	28	8	16	Yes.	75	2.7	70
11	Peaker.	Fine, slaty.	350	93	32	12	No.	100	1.1	240
12	Macksburg 500.	Fine.	700	32	7	26	No.	75	2.45	60
13	First Cow Run.	Medium.	800	100	23	20-50	No.	100	1.0	130
14	do.	Coarse.	120-400	78	28	16	Yes.	100	1.3	45
15	do.	Fine and coarse.	400	17	5	16	Yes.	40	2.35	70
16	do.	Fine.	500-800	17	1	9	No.	45	2.65	160
17	Third Venango.	Fine and tight.	900	65	20	40	No.	85	1.3	320
18	Bartlesville.	Fine and slaty.	500	80	13	31	No.	100	1.25	300
19	First Cow Run.	Coarse.	250	83	31	12-55	Yes.	120	1.55	125
20	Buell Run.	Medium.	400	16	3	10	No.	40	2.5	100
21	Salt.	Coarse.	1,800-2,000	26	5	15	No.	85	3.3	200
22	First Cow Run.	Fine.	500-700	16	4	11	No.	35	2.2	160
23	do.	Medium.	700	17	3	25	No.	20	1.2	60
24	Berea.	Fine.	1,800	40	10	20	No.	50	1.0	200
25	First Cow Run.	Medium.	200	23	7	16	Yes.	50	2.2	70
26	do.	do.	800	28	7	4-16	Yes.	25	9	45
27	do.	do.	700-800	28	11	12	No.	100	1.3	160-235
28	do.	Fine and coarse.	1,400	78	11	12	No.	100	1.3	270
29	Second Venango	Fine.	1,400	12	4	20	No.	25	2.1	140
30	Macksburg 500.	do.	900	40	12	21	No.	65	1.5	90
31	Mitchel.	Medium.	400-500	12	3	12	No.	20	1.7	100
32	First Cow Run.	Coarse.	200	16	7	2-8	No.	75	4.7	120
33	do.	do.	400-500	6	3	6	No.	75	4.7	100
34	do.	Shallow.	Shallow.	6	4	6	No.	75	4.7	100
35	do.	do.	Shallow.	6	4	6	No.	75	4.7	100

On account of having to use gas diluted with air, it is frequently necessary to enlarge the gas intake and reduce the air intake correspondingly. Gas engines are now being constructed which are fitted with special valves for regulating the gas and air intakes conveniently.

The compressor plant should be situated convenient to an adequate water supply, because considerable water is needed to cool the engine and the compressor. The site of the plant should also be selected with a view to distributing the air with a minimum amount of pipe, as this item will comprise a considerable part of the initial cost of installing the process. Moreover, the farther the air has to travel through pipes the greater is the loss of volume and pressure from leakage and friction. On large properties it is considered the better policy to put in several plants rather than to build large central stations.

The compressed air is distributed through 2-inch to 4-inch mains, with 1-inch laterals leading to the air wells. With the distances and the velocities of air used on the ordinary plant, these sizes are large enough and the pressure losses due to friction do not warrant the extra cost of increasing the size of the pipe. The air should be conducted through a cooling system near the compressor (see Pl. I, *B*) and the water drained off in traps, otherwise it will give trouble in the lines, especially in winter.

It is also necessary to have a gas-gathering system from the pumping wells to supply fuel for the compressor plant. These usually consist of 2-inch lines, and the system is essentially the same as on the ordinary lease where casing-head gas is used for fuel or for making gasoline.

The well-pumping equipment can be of the usual kinds, but as the compressed air can be used as a source of power there has been a tendency to put in pumps operated by compressed air. Plates III and IV, *A*, show types of such pumping equipment. The pumps shown in Plate III, *A*, operate on the displacement principle, whereas in the equipment shown in Plate III, *B*, the compressed air is used as in a steam cylinder, the sucker rods being attached to the piston rod. By using compressed air, the engine, pumping power, and housing can be done away with, as well as the shackle rods and the jacks. It is used at Bradford in pump heads (see Pl. III, *B*) and in modified steam engines (see Pl. IV, *A*), because there is not so much loss of power in transmission as with steam, especially in cold weather. Where compressed air is used on a lease, it can be used as a source of power for nearly every purpose.

The oil-gathering equipments are of the usual kinds, and the only effect that the use of compressed air has is to reduce the number of



A. OIL PUMP RUN BY COMPRESSED AIR. IN USE ON A PROPERTY NEAR MALTA, OHIO.



B. "PUMP HEAD," RUN BY COMPRESSED AIR, ON PROPERTY IN THE BRADFORD FIELD WHERE FLOODING IS GOING ON.

the writer is 20 horsepower, and the largest is 185 horsepower. The size of plant necessary will depend on the number of wells on the property, the pressures employed, and the capacity of the oil sand for taking air. Thirty-two of the plants listed in Table 4 average 1.83 horsepower per well (air and pumping wells). The lowest figure is 0.83 horsepower per well and the highest 4.7. The latter plant provides air for other properties. About the same horsepower per well is used for the different pressures (see fig. 9).

In determining the size of a plant consideration should be given to the experience gained on properties with similar conditions, especially those near by, but on account of the variations in the nature of the oil sands, even from one well to another, it is always advisable to make tests, although data on results obtained on properties near by may be available. The usual method of making such tests has been by means of a portable compressor, one of 5 horsepower having been found to be effective in the Appalachian fields. Each prospective air well is tested separately, and the volume of free air which it will take under different pressures is determined. Nearly always the sand will take practically no air until a certain minimum pressure has been exceeded, which is an indication of the frictional resistance in the sand. Also, the maximum pressure at which the sand will take all the air the testing plant can deliver at that pressure may be determined. By these tests data are obtained on the volumes and pressures the wells will require, from which the size of the plant can be estimated. It is, of course, impossible to make the calculation precise, and during the life of a property conditions may change which will modify the first estimates. As a matter of policy it is advisable to put in a larger compressor than is seemingly necessary, in order that there may be reserve power for using higher pressures and larger volumes if found desirable. The plant also decreases in efficiency with continued use, and if the gas becomes lean the actual delivery of horsepower from the gas engine becomes less.

In testing a well the capacity of the testing plant must be known, and the internal capacity of the well itself must be estimated from the size of the casing in the well and the probable size of the shot hole. At frequent intervals careful records are taken of the pressures and the rate at which the well is taking air, so that it can be computed what pressures will be necessary to force a given volume of air into the sand or how much air can be forced into the sand at given pressures. When the test is completed the response of the well to the returning air upon reduction of pressure is noted, and if the air brings back considerable oil it is considered a good indication that conditions are favorable for using the process. This, however, is not a decisive test.

When the tests have been completed they will show what volume of air each well will take at various pressures. The plant should be large enough to force into the sand the volumes of air experience has shown to be desirable. An average of about 10,000 cubic feet of free air per day is used for each well (air and pumping wells), but the volumes required are less for pressures higher than the average pressure (115 pounds) and greater for pressures lower than the average, and may be as much as 20,000 cubic feet per well daily. If the 5-horsepower portable tester showed that the wells which were to be used for taking air each averaged 40,000 cubic feet of air per day at a pressure of 120 pounds and there were to be three pumping wells for each air well, then the average volume required would be 10,000 cubic feet per well, which is the average volume for that pressure. The property would consequently require a plant of not less than 1.25 horsepower per well, and to this figure should be added a factor for reserve power. If there were to be four pumping wells to each air well, higher pressures and greater horsepower per well would be required to force in the same quantity of free air.

PREPARING AIR WELLS.

One of the most important considerations in preparing wells for taking air is not to let the air have access to any formations other than the oil sands, otherwise large quantities of air may escape into the barren strata and be wasted. The reasons for this statement are discussed in more detail in another part of this paper. If the well has a string of casing tightly seated on the top of the oil sand, the air can be let into the top of the casing through a tight head or cap (see Pl. IV, *B*). When the well is not cased in this manner, a string of small pipe or tubing is placed in the well and packed at the top of the sand, as shown in figure 3. One-inch pipe has been used in shallow fields, this sometimes being the only pipe in the hole. Considerable strength is required in the packer to withstand the upward pressure from the compressed air. The usual rubber packers frequently will not hold tight under the pressures employed, and other methods for packing must then be used.

A method of packing that has proved satisfactory for shallow wells is to wrap the pipe with broad strips of burlap or canvas, which is split at the top to form a flare, until the wrapping nearly fills the hole or the casing. The pipe is lowered into the hole to the desired position, some sand is dropped in between the pipe and the walls of the hole to flare out the burlap, and a thin mixture of sand and cement (1 to 1) is poured down outside of the pipe onto the burlap, forming a bridge 5 to 10 feet deep between the pipe and the walls of the hole, so that the pipe is securely packed when the mixture

sets. The burlap is wrapped onto a short joint of pipe which has a left-hand thread at the top, and no anchor is put on the bottom of the pipe. If it is desired to remove the packing, the pipe is unscrewed at the left-hand thread, and the cement drilled out. The first few blows of the tools will probably drive the short joint of pipe through the cement and the hole can be cleared without much effort.

It has not often been considered necessary to shoot the air wells. They should, however, be cleaned out, and sometimes it is advisable to remove the waxy sediments that clog the surface of the sand. Newly drilled wells have the advantage of the sand being perfectly clean and free from waxy sediment.

Occasionally a combination well is made by forcing the air down between the casing and tubing in a pumping well. Such a well can be used as an air well for a time and then be pumped when the air is stopped and the oil comes back under the released pressure.

PREPARING PUMPING WELLS.

In preparing the wells on a property for the use of compressed air, ordinarily no changes need be made in a pumping equipment unless it is old and out of repair. However, the process is frequently installed on properties where the equipment has been allowed to run down because the small profits have not permitted repairs and replacements. Such equipment may not prove adequate to handle the increased production, nor the floating sand which often gives trouble during the first months or years that the process is used. It is also desirable to clean the wells and to put them in condition to yield the maximum production with the least pump trouble and expense. If the application of the process is successful, the additional profits will more than compensate these extra expenditures. Those operators who have spent extra time and money cleaning their wells have usually been repaid by less pumping troubles.

It is sometimes desirable to maintain back pressures in the pumping wells on the oil sand. There are several ways of preparing a well for the use of regulated back pressure, the simplest being to place a reducing valve on the gas-gathering line from the casing head. When pressure is maintained in the well by this means, the formations overlying the oil sand should be cased off so that the gas will not waste in the same way as it would in an air well not cased off. Another method for maintaining back pressures in the wells is shown in figure 4. The tubing ring used with this method is shown in figure 5.

Although the process does not require changing the type of pumping equipment, a logical development will be a greater use of com-

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PREPARING AIR WELLS.

One of the most important considerations in preparing wells for taking air is not to let the air have access to any formations other than the oil sands, otherwise large quantities of air may escape into the barren strata and be wasted. The reasons for this statement are discussed in more detail in another part of this paper. If the well has a string of casing tightly seated on the top of the oil sand, the air can be let into the top of the casing through a tight head or cap (see Pl. IV, *B*). When the well is not cased in this manner, a string of small pipe or tubing is placed in the well and packed at the top of the sand, as shown in figure 3. One-inch pipe has been used in shallow fields, this sometimes being the only pipe in the hole. Considerable strength is required in the packer to withstand the upward pressure from the compressed air. The usual rubber packers frequently will not hold tight under the pressures employed, and other methods for packing must then be used.

A method of packing that has proved satisfactory for shallow wells is to wrap the pipe with broad strips of burlap or canvas, which is split at the top to form a flare, until the wrapping nearly fills the hole or the casing. The pipe is lowered into the hole to the desired position, some sand is dropped in between the pipe and the walls of the hole to flare out the burlap, and a thin mixture of sand and cement (1 to 1) is poured down outside of the pipe onto the burlap, forming a bridge 5 to 10 feet deep between the pipe and the walls of the hole, so that the pipe is securely packed when the mixture

sets. The burlap is wrapped onto a short joint of pipe which has a left-hand thread at the top, and no anchor is put on the bottom of the pipe. If it is desired to remove the packing, the pipe is unscrewed at the left-hand thread, and the cement drilled out. The first few blows of the tools will probably drive the short joint of pipe through the cement and the hole can be cleared without much effort.

It has not often been considered necessary to shoot the air wells. They should, however, be cleaned out, and sometimes it is advisable to remove the waxy sediments that clog the surface of the sand. Newly drilled wells have the advantage of the sand being perfectly clean and free from waxy sediment.

Occasionally a combination well is made by forcing the air down between the casing and tubing in a pumping well. Such a well can be used as an air well for a time and then be pumped when the air is stopped and the oil comes back under the released pressure.

PREPARING PUMPING WELLS.

In preparing the wells on a property for the use of compressed air, ordinarily no changes need be made in a pumping equipment unless it is old and out of repair. However, the process is frequently installed on properties where the equipment has been allowed to run down because the small profits have not permitted repairs and replacements. Such equipment may not prove adequate to handle the increased production, nor the floating sand which often gives trouble during the first months or years that the process is used. It is also desirable to clean the wells and to put them in condition to yield the maximum production with the least pump trouble and expense. If the application of the process is successful, the additional profits will more than compensate these extra expenditures. Those operators who have spent extra time and money cleaning their wells have usually been repaid by less pumping troubles.

It is sometimes desirable to maintain back pressures in the pumping wells on the oil sand. There are several ways of preparing a well for the use of regulated back pressure, the simplest being to place a reducing valve on the gas-gathering line from the casing head. When pressure is maintained in the well by this means, the formations overlying the oil sand should be cased off so that the gas will not waste in the same way as it would in an air well not cased off. Another method for maintaining back pressures in the wells is shown in figure 4. The tubing ring used with this method is shown in figure 5.

Although the process does not require changing the type of pumping equipment, a logical development will be a greater use of com-

When the tests have been completed they will show what volume of air each well will take at various pressures. The plant should be large enough to force into the sand the volumes of air experience has shown to be desirable. An average of about 10,000 cubic feet of free air per day is used for each well (air and pumping wells), but the volumes required are less for pressures higher than the average pressure (115 pounds) and greater for pressures lower than the average, and may be as much as 20,000 cubic feet per well daily. If the 5-horsepower portable tester showed that the wells which were to be used for taking air each averaged 40,000 cubic feet of air per day at a pressure of 120 pounds and there were to be three pumping wells for each air well, then the average volume required would be 10,000 cubic feet per well, which is the average volume for that pressure. The property would consequently require a plant of not less than 1.25 horsepower per well, and to this figure should be added a factor for reserve power. If there were to be four pumping wells to each air well, higher pressures and greater horsepower per well would be required to force in the same quantity of free air.

PREPARING AIR WELLS.

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pressed air in the future as the source of pumping power on leases employing the process. The power is centralized, and the air is readily distributed without much loss in power, or trouble in operation. In many eastern fields the wells were pumped by compressed

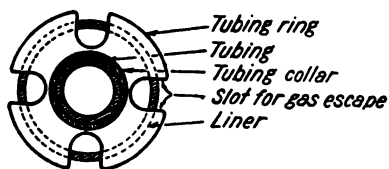


FIGURE 5.—Tubing ring slotted to permit escape of air and gas. (See fig. 4).

air long before the process of forcing compressed air into the sands came into use. At Bradford, Pa., the compressed air is also used to run steam engines, pumping wells "on the beam" (see Pl. IV, A), or in "air heads" (see Pl. III, B).

Air lifts have been tried in the eastern fields but were never satisfactory. Smith and Dunn use air displacement pumps on many of the shallow wells (see Pl. III, A) where the process is employed.

On a few properties some of the wells have displayed a tendency to flow; and it is possible that with the proper application of compressed air, the wells can sometimes be made to flow their production.

PROPORTION OF AIR WELLS TO PRODUCING WELLS.

The proportion of air wells to producing wells will depend not only on the local conditions on each property, but also on the principle on which the process is being operated. If back pressures are being used, different factors enter into the problem than if no back pressures are being maintained in the producing wells. Experience without the use of back pressure indicates that the best practice is to distribute many air wells as uniformly as possible among the producing wells. More recent experience with the use of regulated back pressures in the manner discussed elsewhere indicates that fewer air wells are necessary, and that the wells so used can be chosen by their capacity for taking air rather than because of their central location among a group of producing wells. The operator will decide from the system he is using and from the local conditions which practice to follow.

Where back pressures have not been used the tendency has been to increase the proportion of air wells, the average among 34 properties shown in Table 4 being 1 air well to each 2.6 producing wells. At first consideration the operator is apt to think that as few air wells should be used as possible, thus saving more of the wells for pumping, but experience has shown otherwise.

Figure 6 represents a square tract of 160 acres for which ideal conditions are assumed; that is, the wells are spaced evenly and the character of the oil sand and other conditions are uniform over the

property. There are 25 wells, of which 4 are air wells and 21 are pumped, there being 1 air well to each $5\frac{1}{4}$ pumping wells. The air from each air well passes through the sand to the surrounding pumping wells and presumably affects all the sand between these wells. It is likely, however, that it affects less the strip of oil sand between the line wells and the property line. The diagram illustrates the principle that if there are not enough air wells the oil will not be moved directly between the air wells and the pumping wells, and parts of the oil sand will remain practically unaffected.

The air enters the oil sand at the air well, spreads out, and is distributed among the several adjacent pumping wells. Each pumping well gets but a fraction of the air forced into the air well, and consequently the rate of movement of the air through the sand is much less near the pumping wells than near the air well. If there are four pumping wells to each air well, the effect is like filling a 2-inch pipe through a 1-inch opening. To get a sufficient quantity of air into the sand, it is necessary to use high pressure in the air wells, and this requires more power and occasions greater frictional losses both in the surface equipment and underground. Where the air wells are scattered far apart, the air must travel

long distances through the sand, which also increases frictional losses. With a greater number of air wells, the same quantity of air can be forced into the sand with less pressure, and consequently with a saving in power and frictional losses. Moreover, the compressed air is distributed more uniformly over the property, so that all parts of the sand will be affected. The equipment cost for an air well is much less than for a pumping well; likewise operating expenses and troubles are lessened, and, if the same production can be obtained by changing pumping wells to air wells, a considerable saving may be made.

As a matter of fact, the conditions in the sand are far from being uniform, as is assumed in figure 6, and some parts of the sand will

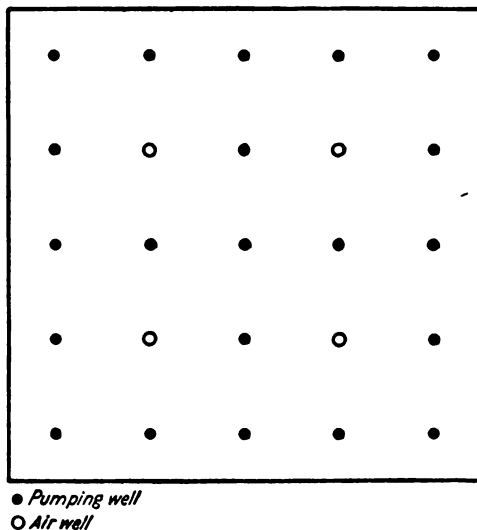


FIGURE 6.—Diagram showing distribution and spacing of air and pumping wells under ideal conditions on a square 160-acre tract.

offer much less resistance to the movements of the air than other parts. The problem is to get the air into all parts of the sand where there is oil and to prevent it wasting through parts where there is little or no oil. The air will take the easiest and the shortest routes between the air wells and the pumping wells, and hence there is a marked tendency for the air to pass around and not affect the tighter parts of the sand or the parts not in the path of the air. Where back pressures are not maintained in the pumping wells, uniform distribution of the air underground is sought by having many air wells uniformly distributed over the property in the manner described.

By maintaining back pressures in the pumping wells, the pressure underground may be built up and eventually the air will find its way into every part of the sand on the property no matter where it originally enters. On this principle, the logical way is to get the air into the sand in the easiest way possible and through the fewest number of wells. The wells where the sand takes the air with least resistance are selected and no more than are necessary to take all the air at the desired pressure, back pressure being maintained in the pumping wells. It is thought that the air will then find its way into the tighter parts of the sand with less resistance, for the air will be distributed through the open parts, and will come into contact with the tighter parts over much larger areas than where the air finds its way into the sand through the walls of "tight sand" wells.

Maintaining back pressures on the producing wells is a recent development, and experience has hardly given a settled policy in regard to the best manner of distributing and proportioning air wells. Some of the factors entering into the problem have been discussed, but in all cases trial and experience will have to determine the best practice on each property whether regulated back pressure is being used or not.

SELECTION OF AIR WELLS.

Perhaps a more important feature in the selection of an air well than its situation is the condition of the oil sand.

The tendency is to use "open-sand" wells for taking air, and "tight-sand" wells for pumping, because the former usually waste too much air when pumped, and the "tight-sand" wells require too great pressure in taking the air and cause large frictional losses. When a pumping well begins to by-pass or waste much air, it had better be changed into an air well. Frequently it becomes necessary to change a well for this reason, and the entire system of air and pumping wells may be rearranged during the life of a property. Figure 7 shows the location of the wells on a property near Penns-

ville, Ohio, and how the air wells had to be arranged in actual practice. Some of the air wells were "by-pass wells," and wasted so much air that they could not be pumped economically. They are arranged in lines apparently in accordance with local variations in the character of the oil sand. On account of the irregularities in the sand, pumping wells on one side of an air well may be practically unaffected, while these on the opposite side may show the effects to a considerable distance.

A few operators advise that all wells on a property be tested at the time tests are made for determining the size of the compressor in order to get an index of the conditions in the sand at each well. Considerable variation will be found from well to well, and these data will lead to a more intelligent determination of what

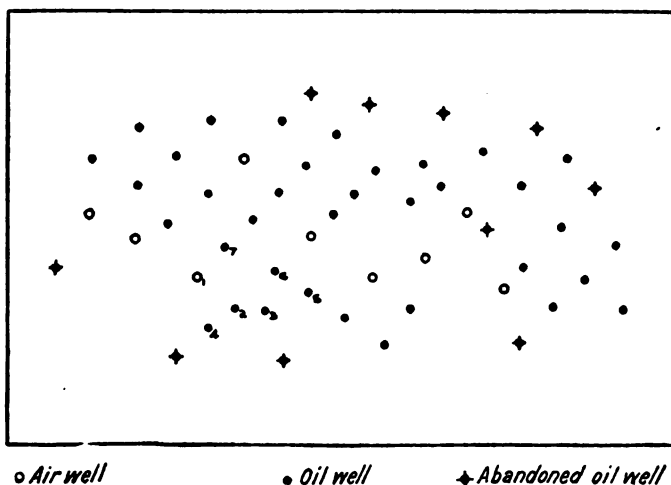


FIGURE 7.—Plat of oil property on "Chesterhill streak" near Pennsville, Ohio, showing irregular distribution of air wells caused by irregularities in the oil sand. Making well No. 1 an air well greatly increased the yields from wells 2 and 3 for a time; then the air "blew through" and made "by-pass" channels. No. 4 was a tight well and was not affected. Nos. 2 and 3 were then shut in and this increased the yields from Nos. 5 and 6. No. 7 and the other wells above were also benefited.

wells to pump, which pumping wells will need regulated back pressure, and which wells will receive air readily. This information is likely to prove of much value during the life of the property.

The condition of the well itself has much to do with the choice of an air well. The well must be in good shape to take air readily, and with no chance of its wasting into other formations. The relative productiveness is also considered, as the producer naturally dislikes to sacrifice a good pump. However, the relative productiveness often changes after the process has been in use, and even old, abandoned wells have been rejuvenated and made producers.

Air wells are placed at a distance from property lines as much as possible, unless an agreement can be reached with the neighbor, because the air will not stop at property lines and may be lost to the operator. Furthermore, the air crossing the property line will move oil with it, at the expense of the user of the process. These considerations are more important where the neighbor is not using the process or his wells are being gas pumped. When only one property uses the process in a field of considerable size, there may be difficulty in building up the pressure, because the air will spread to other properties. This can be largely controlled by placing the air wells centrally on the property and gas pumping the line wells. Where a neighbor is also using the air process it is advisable to reach an agreement with him, if possible, to arrange to force air into the strip between the line wells, which otherwise will be affected only indirectly.

The question has frequently been asked the writer where the air wells should be located with reference to the geological structure of the sand. It is a question not always readily answered, but the following points in regard to it may be considered: When the air forces the oil up a slope it is moved against gravity, whereas if forced down the slope gravity aids in the movement, but in fields like those east of the Rocky Mountains, the slopes of the beds are so slight that this fact seldom need be given consideration among the many more important factors influencing the choice of air wells. At times, however, the oil sand is continuous with an exhausted gas sand. If air is forced into the oil sand, it will tend to move toward the exhausted gas sand carrying with it oil, which will be disseminated in the barren strata with slight chance of recovery. Under such conditions it is better to force air into wells in the former gas sand, build up the pressure, and force oil away rather than toward the gas sand. When the area of the exhausted gas sand is not too great this may be readily accomplished, but there are some pools which are continuous with an exhausted gas sand whose capacity is so great that it may be impracticable to fill it even at low pressures. Properties too close to such areas of exhausted gas sands might have trouble in using the process, owing to the escape of air, but the movement of oil and gas in the sand is so hindered by frictional resistance that the process may perhaps be satisfactorily used fairly close to the exhausted gas sands.

At times it has been found advisable to drill new wells on a property where the old wells have not been advantageously located. The new wells may be pumped or used as air wells for which they are favorably adapted, as the sand about the hole will be free from paraffin or waxy sediments.

UNDERGROUND WASTE OF AIR.

Experience has shown that in the use of the process it is necessary to exclude the air from formations other than the oil sand. Numerous instances have demonstrated that if this is not done, much air may waste into unproductive strata and the efficiency of the process be reduced accordingly. For this reason it has become the general practice to pack the air wells directly above the oil sand. Experience in the gas-producing business has led to a similar practice in finishing gas wells.^a

On both the Dale and the Buck Run properties, which are parts of the historic Joy farm, Morgan County, Ohio, the writer witnessed air coming to the surface in numerous places. Many wells drilled in the early history of the pool had been abandoned and their locations lost, but when the air was forced into the sand they allowed the air to reach the surface as well as to waste into other formations. During the first year the process was used these wells had to be found and plugged. Through these old holes the air got access to formations overlying the oil sand, spread through them, and reached the surface at low places along the creek bottoms. On the Buck Run the air bubbled continuously from joint cracks in the shale along the creek bottom. After the old wells had been searched out and plugged, this escape of air diminished. At the time of the writer's visit to the Poplar Ridge property, near Malta, Ohio, air was still issuing from joint cracks and coal seams, and through laminations in the shale. The writer witnessed an instructive example of the permeability of shales and coal on this property. From a well drilled on a bank some 75 feet above and 150 feet distant from the creek bottom, the muddy water used in drilling passed through a thin streak of coal and also through a platy micaceous shale and showed in the face of the creek bank.

Other instances of air escaping, not witnessed by the writer, have been reported. In one, the air came to the surface in numerous places although there were no old abandoned wells and the oil sand was between 300 and 400 feet deep. The air did not appear at the surface until the process had been in use for over a year. In another case the air passed through the formations above the oil sand and blew out around the casing of a well a thousand feet distant. The oil sand is about 600 feet deep on the property and no sand is reported above it. On a property in Pennsylvania partial failure of the process is attributed by the user to waste of air into old, abandoned wells and into the overlying formations where the air wells had been packed too high.

^a McMurray, W. F., and Lewis, J. O., *Underground wastes in oil and gas fields and methods of prevention*: Tech. Paper 130, Bureau of Mines, 1916, 28 pp.

he permeability of shales has generally been underestimated. y often contain thin seams of sand or porous material, which, in

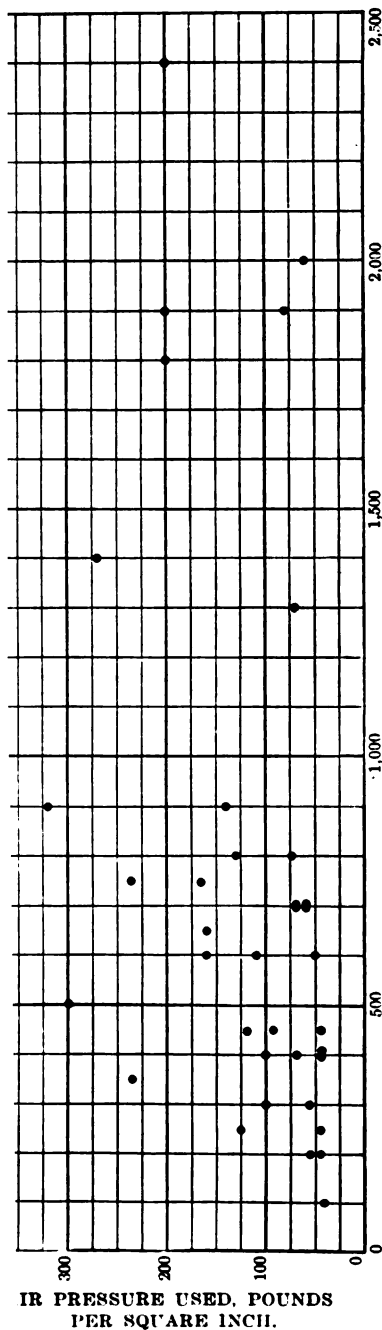


FIGURE 8.—Chart showing relation between air pressures and well depths. Dots represent different properties.

the aggregate, may have a large capacity. Even shales that contain no sandy layers may be permeable along the bedding planes and joint cracks, especially the hard, slaty varieties. There are thousands of gas wells in northern Ohio, Pennsylvania, and New York, particularly along the shores of Lake Erie, whose production is derived from accumulations of gas in beds of this character.

In the cases cited, the migration of the air was made known at the surface, but large wastes may readily take place without surface evidence. Unless there is definite proof that the overlying formations are not permeable, it is advisable not to expose compressed air to them.

AIR PRESSURES USED.

On 41 properties using the process, which include 1,600 wells, the highest pressure used is 320 pounds; the lowest, 40 pounds; and the average is 115 pounds. As high as 600 pounds has been used temporarily.

The pressures used at the present time have not been worked out from a full and systematic study of all the factors involved, and it is not to be assumed that they are the best pressures that might be used. This is a problem

requiring more extended investigation. In the limited experimental

investigations conducted by the writer, it was found that by higher pressures the oil could be expelled from the sand more quickly even when using smaller volumes of free air, but that the ultimate extraction was approximately the same as with lower pressures. Pressure thus appears to be primarily a factor of time and the best pressure to be used can be gaged from the relation between the increased daily production and the increased operating costs or difficulties. In field practice each case will show a complexity of elements often conflicting that must be considered, such as by-passing, effect on the quality of the gas, wastes of air, use of regulated back pressures, etc., so that a study of the special conditions on each property will be necessary, as well as an understanding of the general principles involved.

The pressures used have little relation to the depths of the wells, but are intimately related to the character of the oil sands, as is shown in figures 8 and 9 and Table 4. Coarse porous sands like the First Cow Run take the lowest pressures, whereas fine, tight, or slaty sands require pressures much higher. A large number of the properties operating the Smith-Dunn or Marietta process are producing from the First Cow Run sand in the shallow pools of southeastern Ohio and adjacent parts of West Virginia, where the deep sands are generally of a tighter nature. Where the

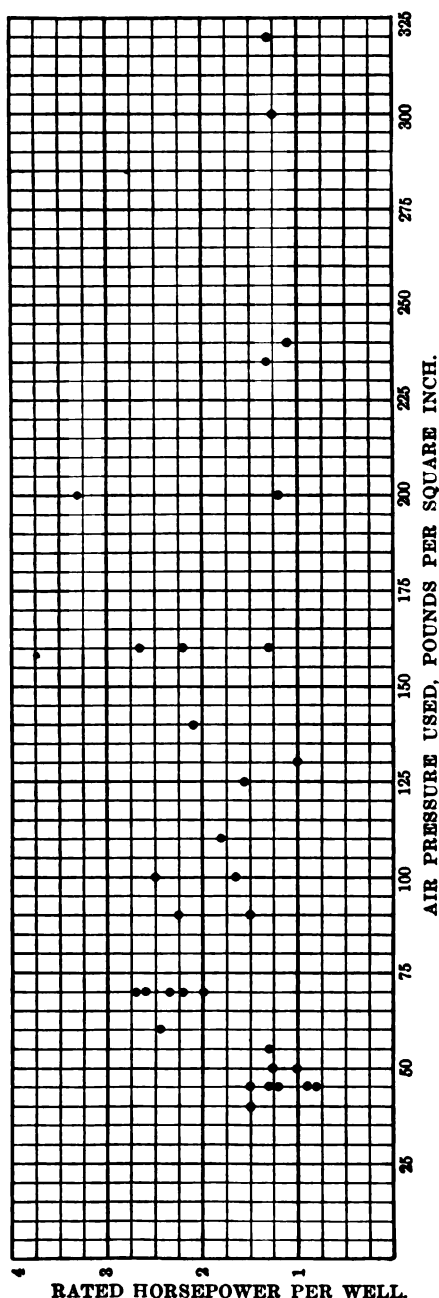


FIGURE 9.—Chart showing relation between air pressures and rated horsepower per well. Dots represent different properties.

deep sands are coarse and porous, low pressures can be used, and where the shallow sands are tight, high pressures are required. For example, wells in the Keener sand in Tyler County, W. Va. (property No. 40, Table 4), are reported to use a pressure of only 50 pounds, although 1,700 to 2,500 feet deep, whereas wells in the Pecker sand (property No. 11, Table 4), in Ohio, require a pressure of 240 pounds at a depth of 300 to 400 feet. Originally the deeper sands had the higher rock pressures, but during the lives of the wells the gas was dissipated until the pressure was no greater than in shallow sands by the time the Marietta process was started. As the deeper sands originally contained the higher pressures, less oil may have been left in the sand, and it is possible this may influence the necessary pressures somewhat.

The pressure necessary will also depend upon the quantity of air being forced into the sand, for if it is attempted to increase the quantity of air, the pressure must be increased correspondingly. For this reason increasing the number of air wells often allows a reduction in necessary pressure. This is illustrated by a property producing from the Pecker sand. There were 93 wells on the property (No. 11, Table 4), 32 of which were air wells, and the pressure used was 270 pounds, but when 5 air wells were started on an adjoining property only 240 pounds was required.

The character and distribution of the contents of the sand likewise affect the resistance to movement, and hence affect the required pressure. An exhausted oil sand, or one containing gas at low pressure, will offer much less resistance than one saturated with oil or water, provided the texture of the sand is the same. A fully saturated sand requires more pressure than one largely drained as shown experimentally, and one containing water requires less pressure than oil, as the frictional resistance is less. However, it may be necessary to use large volumes of air to get results where there is less oil, and hence higher pressures. The required pressure varies from well to well, and from property to property, in accordance with conditions at each locality. Often two adjacent wells producing from the same sand will show wide variations. For example, it is reported that of two adjacent wells, one took the full capacity of a testing plant at 40 pounds, whereas the other required 150 pounds.

The pressures used are not constant and will vary throughout the life of the property. It is often found advisable to change the pressures, as underground conditions change because of the removal of oil. It is likely that greater pressures will be required as the process continues to be used, especially as back pressures may be used on the pumping wells, and hence correspondingly higher pressures must be used at the air wells. The movement of the air through the sand is caused by differential pressure, and whenever back pressures are

maintained at the producing wells, the pressure at the air well should be increased also. If there is still natural pressure from gas in the sand, higher pressures will be required. For example, if the natural pressure is still 50 pounds, a pressure greater than 50 pounds must be used at the air well to get results.

There is always a minimum pressure below which the oil sand will take but little air, or not enough to appreciably increase production. There is also a maximum pressure which can not be exceeded without enlarging or increasing the efficiency of the compressor plant or the conditions of operation. This maximum pressure shows that a balance has been reached between the volume of air being forced into the sand at that pressure, the volume of air issuing from the pumping wells or being wasted underground, and the frictional resistance in the oil sand. By enlarging the capacity of the plant or by reducing waste of air and gas at the pumping wells and underground or by maintaining back pressures in the pumping wells, the maximum pressure may be increased.

In practice the preliminary tests indicate approximately what pressures will be required to force certain volumes of air into the sand. After the process has been put into actual operation it is determined experimentally what pressures and volumes are most efficient. In general, more oil can be recovered by increasing the volume and pressure, although some operators report that this is likely to cause by-passing and waste of air. The best practice seems to be to build up the pressure, gradually noting the effects on production, and in this way determine the maximum efficiency from both the increase of production and the costs of operation.

Very often the pressure can be reduced after beginning the process, it having been found that in many instances the sand will take the air more readily after movement through the sand has started. One producer in West Virginia reports that a pressure of 600 pounds was necessary at the start, but later 200 pounds was sufficient. This is an extreme instance, for usually any reduction of pressure reported is comparatively much less. In the later life of the properties it may be necessary to increase pressures once more.

There is always a loss in pressure between the compressor and the air well which should not be more than a few pounds if the fittings are tight, the pipe not too small, or the air lines too long. In the oil sand there is a considerable loss in pressure between the air wells and pumping wells, but if the latter are closed in, the pressure in time will build up. There are few records of closed-in pressures in pumping wells. On a property where the pressure used was 300 pounds a pumping well showed a closed-in pressure of 80 pounds within an hour. When the process is stopped, the pressure quickly reduces at first and then more and more slowly.

On a property at Bradford, Pa., where a pressure of 80 pounds had been in use, and the production had been increased about seven times, production returned to normal in three months' time after the input of air was stopped. On a property using a pressure of 240 pounds the pressure dropped to 145 pounds in four days after stopping the air. The curve in figure 10 is plotted from a gage record on an air well (on property No. 6, Table 4) and shows how the pressure in the air well dropped after the pumping of air was stopped, the closed-in pressure of the oil wells on the property being about 30 pounds.

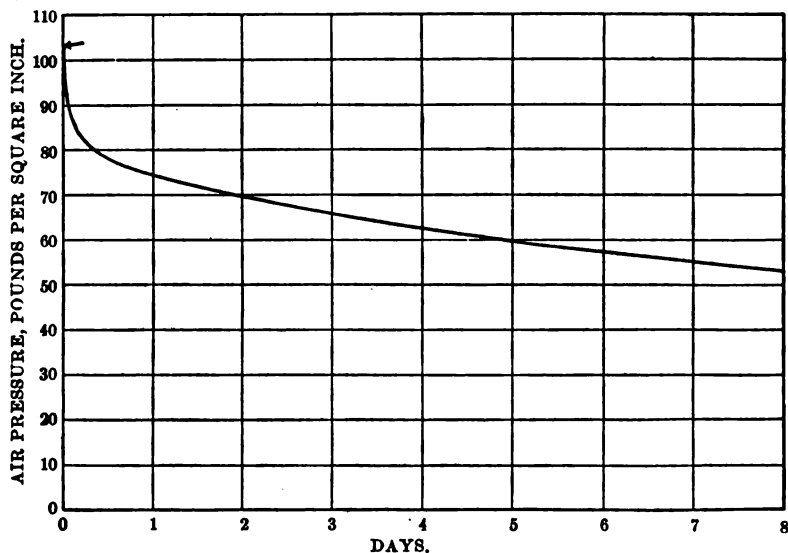


FIGURE 10.—Curve showing the declines of pressure in an air well after stopping the input of air. Plotted from recording gage chart on property No. 6, Table 4. The decline represents the equalization of pressure in the air well and the closed-in pressure of the oil wells, which was about 30 pounds.

To overcome the different rates at which different parts of the oil sand in a property take air because of the variations in the nature of the sand, two methods are possible. One is to regulate the pressure at the intake—that is, at the air wells—the other, at the producing wells where the air escapes. The latter method, which is thought to contain the best principles, is described elsewhere. The pressures at air wells taking air too readily can be regulated by reducing valves in the air lines or by having two systems of air lines carrying different pressures. This can be done when there are two compressors on the property working at different pressures or by having the two cylinders of a two-stage compressor deliver air at different pressures. The purpose of regulating the pressures at the air well is to more nearly equalize the volume and energy delivered to the sand at different parts of the property,

otherwise one part of the property may receive little air and be practically unaffected. In regulating the pressures at the air wells some mechanical difficulties are encountered, and this method is not considered to be as efficient as regulating the pressures at the producing wells and is seldom used.

VOLUMES OF AIR USED.

On an average about 10,000 cubic feet of free air is used per well daily; that is, 30,000 cubic feet of air is forced into an air well daily on a property where the proportion is one air well to two pumping wells and 40,000 cubic feet daily where the proportion is one air well to three pumping wells. The minimum is about 5,000 cubic feet of air per well daily and the maximum about 20,000 cubic feet. Where the pressures are low, larger volumes are used, and where the pressures are high the volumes are small. In thick, open-textured sands, or sands subject to by-passing, the volumes will be large; whereas in tight sand high pressures and small volumes will be used. The operator may largely control the volume of air by changing the horsepower used per well.

As brought out experimentally, larger and larger volumes of air will be required to expel each additional barrel of oil from the sand, consequently with the continued extraction of the oil, the cubic feet of free air necessary on the property will be increased. As with the pressures, it is by no means certain that the present practice in regard to volumes of air used are the best possible, and hence further investigations may show that the figures cited do not represent the greatest possible efficiency even for the districts where used; furthermore, it is probable that outside of the Appalachian field greater volumes will be required, which may be gaged roughly by the comparative quantity of oil that has been produced per acre of oil land.

POWER REQUIRED.

The energy used in practice appears to be much the same for the different pressures and volumes used, and consequently for the different kinds of oil sands, as is shown by figure 9 on page 53. According to the limited data on which this figure is based, there is some evidence that the moderate pressures may require more horsepower per well, and hence more energy than for the higher pressures and tighter sands. But the data are too few at this time to establish general conclusions, and possibly future experience may alter the practice.

If the conclusions indicated by figure 9 can be accepted they show that the energy or horsepower required per well will not depend on

the character of the sand so much as upon other factors. In tight sands the pressures are increased, but the volumes are decreased correspondingly, as is indicated in the figure, so that a smaller volume of air suffices. The resistance is undoubtedly greater in the tight sand, but this may be largely compensated by greater efficiency of expulsion, for in the open sands the energy is more likely to be wasted by the air slipping through parts of the sand without doing work. This indicates that the energy or horsepower required per well depends more on the thickness and degree of saturation of the sand, the wastage of air, and what has been termed the "efficiency of expulsion," or proportion of energy actually expended in moving oil. For the same kind of sand and for conditions otherwise similar an oil sand 20 feet thick would require twice the volume of air to maintain the same pressure as a sand 10 feet thick, and consequently twice the horsepower per well. The wastage of air and pressure in the plant or the waste of air underground through improperly finished wells or by escape to other properties will likewise necessitate the use of more power, as will by-passing and other forms of inefficiency within the oil sand which reduce the proportion of the energy actually expended in moving the oil.

The results shown in figure 9 are based upon the rated horsepower of plants in actual use. In all probability many of the plants are unnecessarily large, whereas others are inadequate in size. Furthermore, the actual delivery is seldom the same as the rated horsepower, and in practice many plants fall far below the rated power, owing to inefficiency in both the compressor and the gas engine.

HOW THE AIR MOVES THE OIL.

The three physical principles upon which the compressed air moves the oil through the sand are, first, by direct pressure; second, by the air going into solution under pressure near the air wells and later expanding near the pumping wells; third, by the carrying of vapors.

Many producers believe that the air displaces the oil and pushes it ahead in a solid body in the same way that a body of oil appears to be collected and driven ahead of a "water drive" in the Bradford field. At Bradford a well in the path of an approaching flood gives no indication of the proximity of the flood until it nearly reaches the well, although it may be very close, as shown by figures 27 and 28, printed on page 98. The production of oil suddenly increases and is maintained for a variable period, after which the volume of water increases quickly and ends the life of the well. In the Smith-Dunn process the air reaches the well first and is followed by an increase of production, which takes a few months to several years to reach a

maximum, and during the time the process is used air is passing through the sand continuously. In the groups of wells in the Bradford field (see fig. 32, p. 115) around an air well, wells 7 and 8, respectively 1,500 and 2,150 feet from the air well, were affected to the extent of having 26 and 10 per cent of air in the gas, yet the oil production remained unaffected though the production of closer wells was increased ninefold. These facts show that there is no "air drive" comparable to a "water drive" and in the sense meant by the producers mentioned and that the air does not work solely on the displacement principle.

The writer's theory is that the oil is probably worked into a froth by the air, and bubbles are continually forming and breaking in the pores of the sand, all the time moving with the air toward the pumping wells. This condition is indicated by experiments.

ENERGY UTILIZED IN MOVING OIL.

In passing through the oil sand the full energy of the compressed air is not expended in actually moving oil. Some of the energy is used in overcoming the frictional resistance in the sand, and much of it is wasted, the air slipping through the sand without moving oil. This waste of energy is comparable to slippage in an "air-lift" for pumping oil or water. It is "by-passing" on a small scale and will be greatest in a coarse open sand or with a light oil of low viscosity and increases enormously with the progressive extraction of the oil from the sand; consequently, although the frictional resistance will be higher in a fine, tight sand, or with heavy, viscous oil, the waste of energy will be less and the actual proportion expended in moving the oil may be but little more. This is suggested by figure 9, which indicates, so far as the limited data permit conclusions, that no more energy has been required for tight sands using high pressures than for open sands using low pressures, and is also indicated in experiments.

The proportion of energy actually expended in moving oil may, as was previously stated, be conveniently referred to as the "efficiency of expulsion." When the sand is full of oil, the efficiency will be high; but it will become less and less as the sand is depleted, because the slippage will increase. It may be expected that the efficiency of expulsion will decrease with time as the oil is removed, in accordance with experimental results. This loss of efficiency can be combatted by increasing the volume of the air passing through the sand, or possibly by alternately building up and releasing the pressure. By increasing the volume, the air is forced into new passages through the pores of the sand not affected previously. By building up the pressures it is expected that the oil in the

tighter parts of the sand will absorb and become charged with compressed air; and when the pressure is released the air will expand and force this oil in the direction of the pumping well or toward the air passages and lines of least resistance in the formation, where the pressure will be reduced most rapidly. An intermittent building up and releasing of pressures would tend to cause the oil to move toward the air passages and diminish "by-passing" and loss of efficiency. It is probable that the decline in production shown by some of the properties using the air process (see production curves on pp. 68 to 74) represents loss in efficiency of expulsion more than depletion of the oil.

TENDENCY TO FOLLOW CHANNELS OF LEAST RESISTANCE.

The passage of the air through the oil sands, as previously stated, is along the shortest lines of least resistance between the air wells and the pumping wells. If the sand were uniform in character the air would travel directly from an air well to each of the adjacent pumping wells through a comparatively narrow passage, leaving a large part of the sand body practically unaffected, but the variations in the character of the sand cause the air to travel through irregular and devious channels. In numerous instances, pumping wells on one side of an air well have remained practically unaffected, while the air traveled through roundabout channels and reached wells in most unexpected places. By-passing is also a common phenomenon, the air following a former gas-bearing stratum, or the nearest exhausted, coarsest and most porous layer in the oil sand. The by-passing channels may take all the air that the plant can deliver so that very little enters the other parts of the sand. This tendency to follow channels, that are likely to constitute but a minor part of the sand body, will be the most serious problem to overcome in the later life of all properties. Even if by-passing does not cause trouble when the process is first started, eventually the oil will be expelled from the channels of least resistance, and by-passing established. This has occurred many times in practice, and wells which gave good response at first have "blown through," the production decreasing at the same time. If reliance had to be placed solely upon the driving power and the direct pressure of the air, the only recourse for the producer in such a case would be to increase the volume and the pressure of the air going into the sand so as to force the air to enlarge the channels and thus affect a larger part of the sand body. This would become more and more difficult to accomplish, and sooner or later the practical limits would be reached, although a vast quantity of oil might remain in the rest of the sand.

PRINCIPLE OF SOLUBILITY OF GASES IN OIL.

Because of the solubility of gases under pressure and their later expansion upon release of pressure, it becomes possible to affect the oil in all parts of the sand. The air is absorbed by the oil at the points of high pressure near the air wells, and moves through the oil toward points of low pressure in the same way that the gas, originally dissolved in the oil, flowed toward the wells when they penetrated the oil sand. It thus becomes possible to recharge the sand so that the oil, regardless of its location, is stored with energy once more. This offers a solution for the problems arising from the variations in the sand body and the tendency of the air to follow the channels of least resistance.

OIL IN TIGHTER PARTS OF SAND.

It is often contended that the tighter parts of the sand contain only a negligible quantity of the oil and that practically all the production is derived from the thin pay streaks. The author does not hold to this view, for although the greatest production may have come from the pay streaks, especially during the early life of the well, the amount of oil held in the other parts of the sand, when the property has become so depleted that the air process is necessary, may be relatively many times more. Just as a tight-sand well comes in at a lower production, but holds up better than an open-sand well, so in the later life of a well with a thin pay streak it may be the tighter parts of the sand that yield most of the production. It is often reported that in shooting old wells greater response is gotten from the tighter parts of the sand. The rich pay streak is apt to represent but a small part of the total thickness of the sand, often but 2 or 3 feet in a bed ten or more times thicker, so that although the porosity of the pay streak may be greater than the rest of the sand the total oil content may be much less.

ALTERNATE CHARGING AND DISCHARGING OF WELLS.

A test which has been made repeatedly is to force air or gas into a well for a time and then to release the pressure. The air or gas usually comes back with much vigor; at first it may be entirely free from oil, later it will show oil vapors, and at last, in most wells so treated, oil is brought back in considerable quantities. Sometimes oil appears within a short time after the pressure is released, at other times it may take several days, and occasionally a long time for the oil to come back. The writer witnessed one instance in which a well, into which air had been forced for over a year, within

an hour after the pressure had been released was spraying oil. In some instances wells have flowed oil with the return of the air on release of the pressure. This seems to be direct proof that the air is not acting solely as a driving force, but has gone into solution in the oil and upon the release of pressure at the air well expands and expels the oil just the same as when the well was first drilled into the sand and the oil was charged with natural gas. On one property near Marietta, Ohio, so small that elaborate equipment is not warranted, production is successfully obtained by alternately charging and discharging the wells.

USE OF BACK PRESSURES.

The use of regulated back pressures is based upon the principle of charging the oil with air under pressure as well as overcoming the differential movements of oil through the tight and open parts of the sand. It is the writer's belief that this principle will have to be resorted to more and more in the later life of the property in order to obtain the oil from parts off of the channels of migration or pocketed in the sand. By alternately charging the oil with compressed air and releasing the pressure the field would go through a series of producing stages, as has been accomplished experimentally. If the field were shut in and the pressure built up until all the pores of the sand were filled with air at high pressure, and all the oil was charged with air, it is to be expected that when the pressure was released the conduct of the field would be similar to what it was when first opened up. The productions, of course, would be relatively smaller and the exhaustion relatively faster, but after the air had been expelled the sand could be charged again with air and the process repeated.

To date the only special applications made of the principle of the solubility of air under pressure in oil have been by building up the pressure in one well and later releasing it, or by carrying regulated back pressures on a few troublesome wells. The stage has not been reached on any property where it has become necessary to charge and discharge all the wells on the property in the manner considered. The practical operation of the process has not been sufficiently developed, but it is believed that in the future the producers will have to rely on this principle more and more, and practical methods of applying it will have to be worked out. It may be practical on a large property to alternately charge one group of wells while the other wells are producing, or by maintaining back pressures on all the pumping wells and using a correspondingly higher pressure on the air wells so as to get the same differential pressure between air and pumping wells it may be practical to charge a sand

while production is maintained, and at intervals the pressure can be released. For example, in a property using an air pressure of 100 pounds back pressures on the pumping wells could be raised gradually to 200 pounds, while the pressure at the air wells was increased to 200 pounds, and this pressure maintained until the operator was satisfied that all of the oil sand was charged. By discontinuing the back pressures the air in the sand at pressures of 100 to 200 pounds would be released and would start the oil moving from all parts of the sand toward the pumping wells. To apply such a method, however, on a small property might not be practical except with the cooperation of neighboring producers.

CHARACTER OF THE GAS FROM THE WELLS.

The analyses of the air-gas from oil wells where the process is used, given on page 80, show that it contains appreciable quantities of gasoline vapors. Theoretically it might be possible to vaporize and remove the lighter fraction, even from the oil wetting the sand grains, by passing air through continuously, which has been accomplished experimentally. It is interesting to note this was attempted in 1894 in parts of the Trenton limestone pools of Indiana and northwestern Ohio.* The principle is of practical importance, since it causes the enrichment of the air-gas which must be used for raising power. On some properties there is an excess of air-gas rich enough for extracting gasoline, and by the absorption process for extracting gasoline from natural gas this may become a profitable source of revenue in the future.

"BY-PASSING" AND "BLOWING THROUGH."

"By-passing" and "blowing through" of air are two of the greatest difficulties to be overcome in the successful use of the Smith-Dunn or Marietta process. By-passing is where the air takes the line of least resistance, usually along the top of the oil sand through a former gas stratum or a drained part of the sand. Blowing through is where the air removes most of the oil from the most porous part of the oil sand and establishes by-passing.

Blowing through does not make itself evident when the process is first started. A well will be producing much oil and very likely be one of the best wells on the property, when a considerable increase in the quantity of air wasted will come about, showing that the most porous part of the sand, which is generally the former pay streak, has been cleared of oil and is letting the air pass through with little restriction. The yield of oil generally decreases, and the well will

* Jordan, E. T. J., Report of State supervisor on natural gas: 19th Annual Report, Dept. of Geol. and Nat. Resources of Indiana, 1894, pp. 134-136.

become of little value as a producer, while it wastes so much air that it will seriously affect the production of the whole property. It may take several months or even several years before a well will blow through. It may be expected that in course of time most of the wells will be subject to this trouble to some extent, and if there were no way of overcoming this difficulty the compressor plants would have to be enlarged continuously, as first the most porous layers and then the next most porous layers were blown through in succession until it became impracticable to enlarge the capacity of the plant further. It is thought that blowing through is one of the causes of the decline in production of some of the properties using the air process longest, and Messrs. Smith and Dunn report that they have favorably influenced production on properties so affected by taking means for overcoming this difficulty.

By-passing becomes evident soon after the process has started. The effect is the same as in blowing through. Energy is wasted, for the air passes through the sand without doing work, and so much air may escape at the pumping wells subject to by-passing that it will seriously affect the success of the process. Practically all the air forced into the sand may be diverted through these by-pass channels so that the parts of the oil sand containing the most oil may receive no benefit. Not only is the oil production affected, but the gas becomes lean and may be made unfit for use. Lean gas on any property at the present time is, because of the comparatively recent date of introducing the process, an indication that the air is not coming into contact with oil and is not doing its full quota of work.

The simplest method of overcoming this trouble is to shut the well in or to change it into an air well, and frequently it becomes necessary to make these changes after the process has been started, for it is better to sacrifice a small producer than to permit the escape of too much air, as by so doing the production of the other wells is affected. Another method which limited use indicates will be successful is to use regulated back pressures as outlined elsewhere in this paper. Sometimes it is possible to pack or case off the by-pass part from the rest of the oil sand in a new well that has not been shot.

USE OF REGULATED BACK PRESSURES.

The principles of maintaining back pressures on pumping wells have been discussed previously. This method is used for overcoming the difficulties caused by the irregular character of the oil sand, by which the variations in frictional resistance in different parts of the sand are more nearly equalized by holding pressures on those wells where the resistance in the sand is slight. The excessive escape of air from wells subject to by-passing is prevented, so that the air is distributed more evenly over the property and is made to do more work.

The other principle upon which the use of back pressures is based is the building up of pressure in the whole area drained by the wells until the oil in all parts of the sand is charged with compressed air, so that when the pressure is released the oil will be expelled by the expanding air from the tighter parts of the sand.

The use of regulated back pressures is a more recent development in the Smith-Dunn or Marietta process, and although they have not yet been used extensively, the results are encouraging, so that it seems likely that they will be used extensively in the future. Wells which formerly wasted large volumes of air have been controlled and made good producers. In one instance the escape of gas has been reduced from several hundred thousand cubic feet daily to the average amount, the rest of the wells on the property being correspondingly benefited.

The simplest method of maintaining back pressure in a well is to regulate the escape of air-gas from the casing head. A reducing valve is placed on the air-gas line and is regulated until the excessive escape of air-gas is reduced to the average for the rest of the wells on the property. The back pressure necessary will vary with every change of conditions and must be determined experimentally, though by closing in the well and noting the pressure a good index of the back pressure required will be obtained, which should be nearly the same as the pressure of the well when closed in. Maintaining back pressure by this method in a pumping well is apt to decrease the yield somewhat in the same way that production is usually decreased when back pressures are held on flowing oil wells, but this is more than compensated by the beneficial effect on the other pumping wells, for the air that formerly had passed through the sand without expending much of its energy in moving oil is now forced into other parts of the oil sand and made to do more work.

Another method that has been used to maintain back pressures is shown in figure 4, on page 45, and is called maintaining "fluid back pressure." In this method a liner perforated at the bottom is set into the oil sand and packed off above the top of the sand. The tubing is set inside the liner and rests on a tubing ring at the top of the liner. This tubing ring is perforated or notched so that gas may escape from between the liner and the tubing (fig. 5, p. 46).

The working barrel is set high with a flood nipple below, and when the fluid is pumped down to this point, air is let in and the fluid can not be lowered below this level. The flood nipple is so placed that the weight of the column of fluid held in the liner between the top perforations and the fluid nipple approximately equalizes the pressure of the well when closed in. If the pressure is 25 pounds, the flood nipple should be placed about 60 feet above the top perforations in the liner. In a well finished as shown in figure

4, the air-gas accumulates below the packer and bears down on the fluid in the well, forcing it up into the liner and the tubing. Before the fluid has accumulated to such a height that the pressure head is equal to the air-gas pressure, the air-gas may escape readily, but after its pressure has been counterbalanced by the fluid column, the air-gas is sealed in and little can escape. As more oil accumulates it rises equally in the shot hole and in the liner, so that the same difference in level and consequently the same fluid pressure is maintained against the air-gas pressure, though the fluid pressure at the bottom of the oil sand is increased somewhat. In this manner the oil can accumulate until the shot hole is filled. When the well is pumped, the fluid levels within the liner and in the shot hole are lowered equally until they have reached the flood nipple and almost to the top perforations in the liner, respectively, whereupon the well ceases to pump oil.

Instead of finishing the well with a liner, a string of casing can be landed at the bottom and shut in at the top, the tubing and the flood nipple being placed in the same positions in regard to the fluid column as in figure 4. This method has the advantage that the pressure can be gaged easily and continuously, and the position of the flood nipple be changed readily, but unless another string of casing is landed on the top of the sand the air may escape into other formations, or shale may slough off the walls and fall into the hole. Sometimes the flood nipple is omitted and the working barrel is placed low in the well. When the fluid is pumped below the counterbalancing level there is a sudden inrush of air gas which brings in oil from the sand into the hole. When pumping is stopped the fluid rises again and stops the rush of air. By this method a sudden release of air gas takes place every time the well is pumped down.

As the conditions change in the field, it will be necessary to change the back pressure used, from time to time, as varying conditions necessitate.

USE OF GAS PUMPS IN CONNECTION WITH THE PROCESS.

Gas pumping is not commonly conducted in conjunction with the Marietta air process. Where necessary the line wells are gas pumped to protect the property against drainage, especially if the neighboring wells are being gas pumped or where they are not using the air process and there is a movement of air through the oil sand toward the adjoining properties. Gas pumping may occasionally be desirable at wells where the sand is much tighter than the average on the property. The tighter parts of the sand require greater pressure to force the oil through them, and by using the gas pump on wells where the sand is tight the air will be drawn toward these

wells and the movement of the air through the oil sand may be more nearly equalized over the property.

The producer at first is apt to consider the suction pump as being a favorable aid to the air process, and that by applying pressure at one end with the compressed air and suction at the other end with the gas pumps the efficiency can be materially increased. The practical limit of a gas pump is only 12 or 13 pounds below atmospheric pressure, and this additional difference in pressure can be obtained far more readily by applying 12 or 13 pounds more pressure at the air well. The principal function of the gas pump, as has been shown, is to permit more gas to expand from solution in an oil sand where the pressure has been reduced almost to atmospheric. The conditions where air is being used are not the same as where gas pumping has been successful. Gas pumping would accentuate troubles from by-passing unless limited to the "tight-sand" wells and is in opposition to the principles of maintaining back pressure in the pumping wells, a method to which the producers will probably be compelled to turn more and more in future.

TIME NECESSARY TO INCREASE PRODUCTION.

The first effects from forcing air into the oil sand are shown by the gas. The volume is increased considerably, and the oil produced becomes livelier and shows more of a "bead." These results are usually noted soon after the pumping of air into the sand is begun, but the actual increase in yield of oil occasionally may be delayed for several months. Usually the increase of oil is closely preceded by an increase of water, and sometimes a well will produce water even if it never has before. The time required for an increase in oil production is variable, as is shown in the production curves presented in figures 11 to 24 of properties listed in Table 4. In one instance the production was increased $3\frac{1}{2}$ times by the third day, but this is exceptional, and in other instances it has taken many months. The increase may be sudden, as in figures 17, 19, and 21, or it may be built up gradually, as in figures 16, 22, 23, and 24.

The producer should not be discouraged until the process has been given a thorough trial. The texture and thickness of the sand, the size of the field, and whether the oil sand is overlain by former gas sand, the capacity of the compressor plant and whether it is run continuously or not, the distance between wells and the relative depletion of the oil sand, all influence the time necessary for the wells to respond to the air. Comparatively, tight sands respond more slowly than open sands, but if the sand has a large capacity it may take some time to fill it up and build up a pressure sufficient to influence production. This is especially true where the top of the sand was

formerly gas bearing, or where the air escapes through the sand to other properties. If the wells are far apart, it will take longer for the air to influence production, and if the compressor plant is not

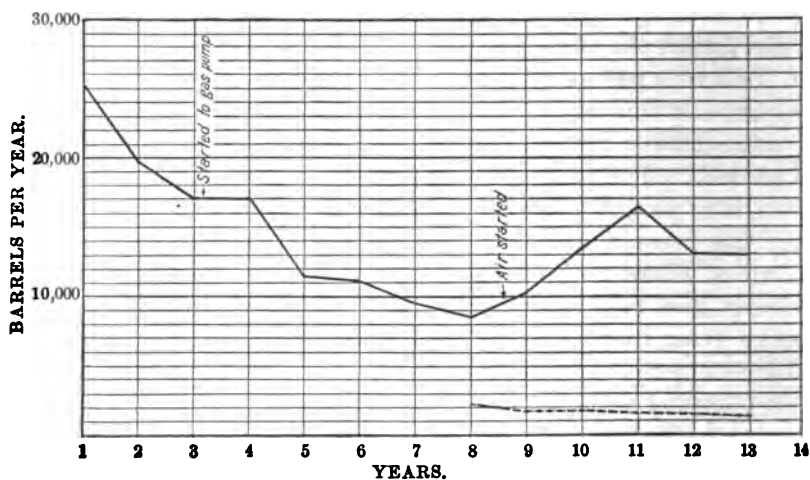


FIGURE 11.—Production curve of property No. 1, Table 4. This is the first property on which Smith and Dunn used compressed air. The lower broken line is the production curve of a part of the property on which air was not being used. Note the effects of gas pumping.

large enough, much time may be needed for it to build up pressure in the sand. It is not necessary that the full quantity of gas extracted from the sand be replaced by air at the same pressure, for ordinarily

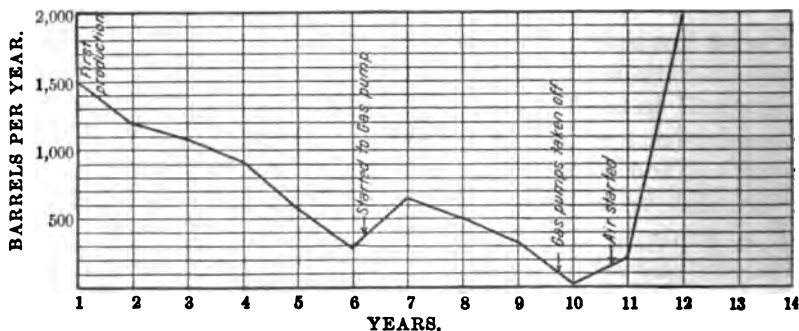


FIGURE 12.—Production curve of part of property No. 9, Table 4. Yield was always small and the property was practically abandoned at the time the use of compressed air was started. Note the effects of gas pumping, and that the compressed air raised the production higher than the initial year of the property.

it is possible to employ the air process at a lower pressure than was originally found in the field. There may be places, however, where the capacity of the former gas-bearing sand connected with the oil sand is so large that it is impracticable to use the process.

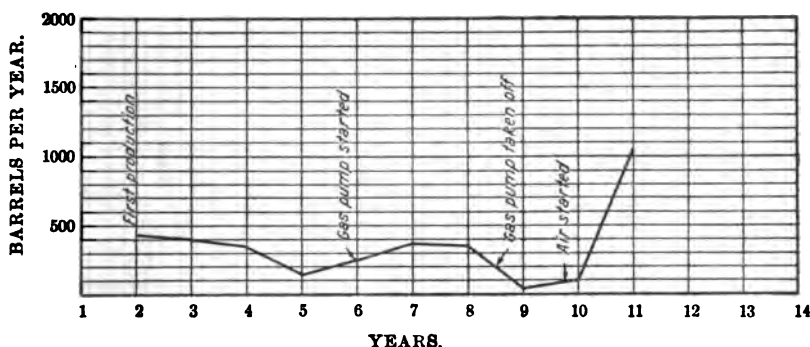


FIGURE 13.—Production curve of part of property No. 9, Table 4 (see fig. 12). The use of compressed air more than doubled the production from what it had been for the first year the property produced. Note the effects of gas pumping.

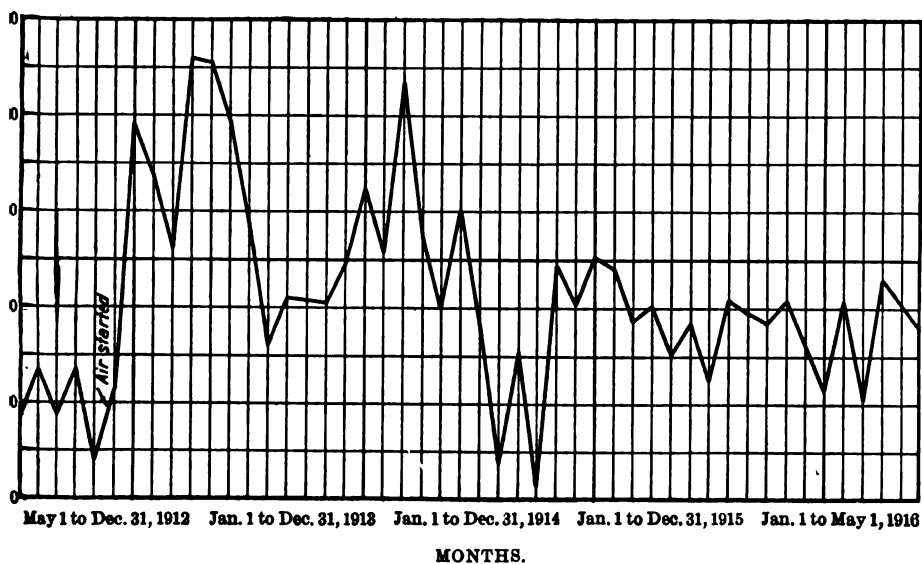


FIGURE 14.—Production curve of property No. 2, Table 4. Note the quick response to the use of compressed air and the declining production after the sixth month.

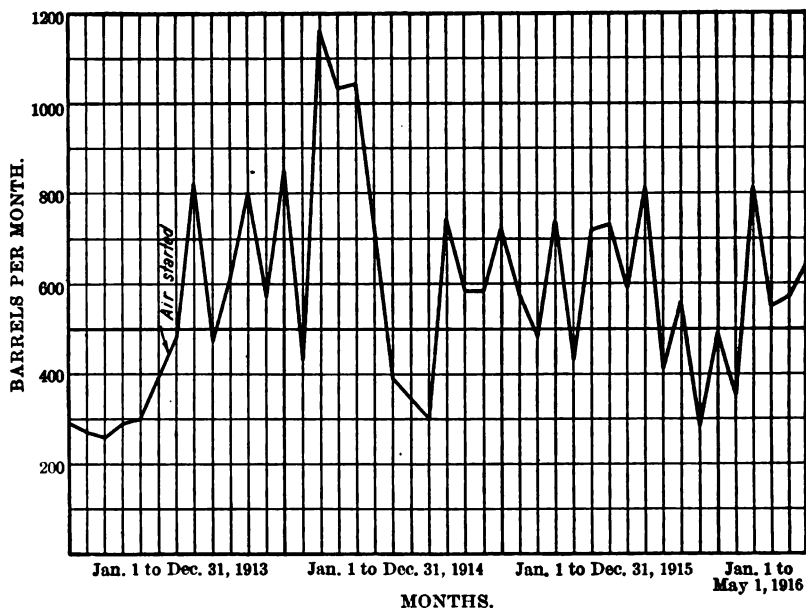


FIGURE 15.—Production curve of property No. 4, Table 4. This is part of the Joy farm, Morgan County, Ohio, and was first drilled in 1861.

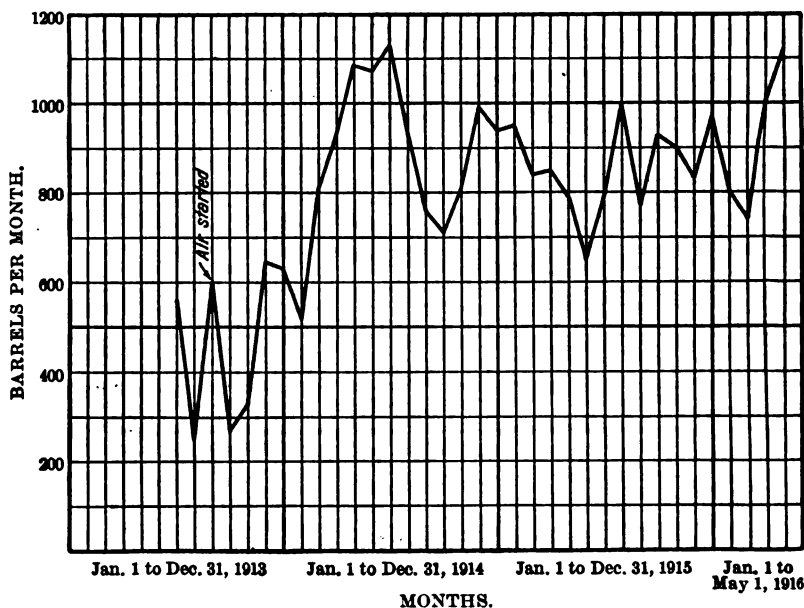


FIGURE 16.—Production curve of property No. 8, Table 4. It took six months to increase production, but at the end of three years the production was still increasing. The upper part of the sand is very coarse and formerly gave large gas flows.

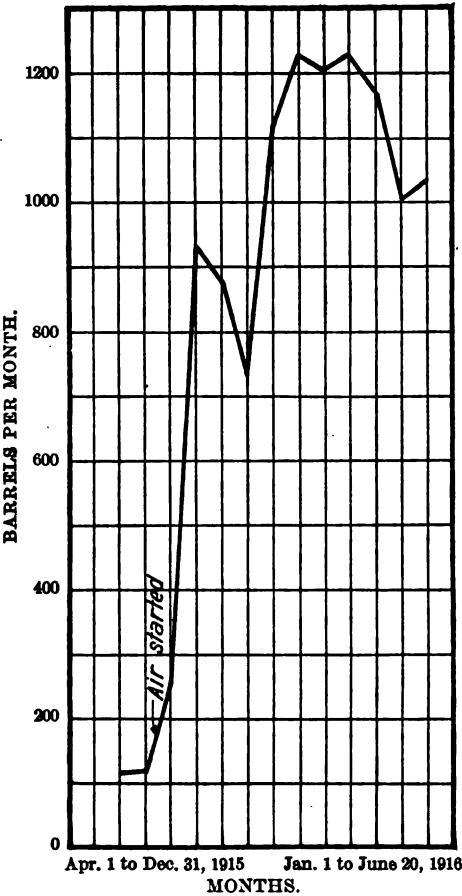


FIGURE 17.—Production curve of property No. 36, Table 4. Within three days production had increased three and one-half times, an unusually large increase. The wells were drilled in the latter part of 1910.

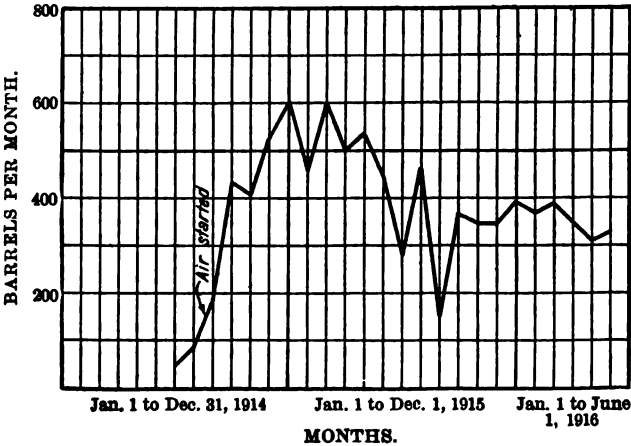


FIGURE 18.—Production curve of property No. 16, Table 4. Oil sand is fine, requiring pressure of 160 pounds, yet the production was increased rapidly.

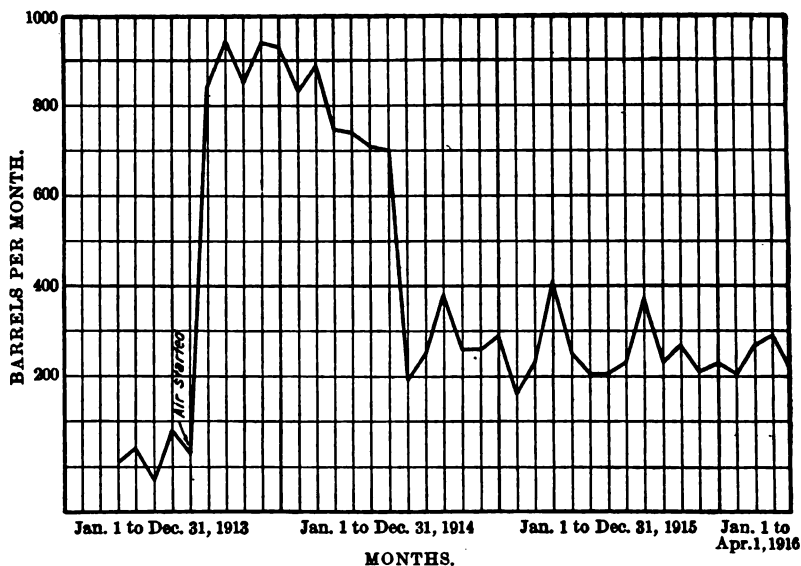


FIGURE 19.—Production curve of property No. 5, Table 4. Production is from the Macksburg 500-foot sand, in which a number of failures have been reported.

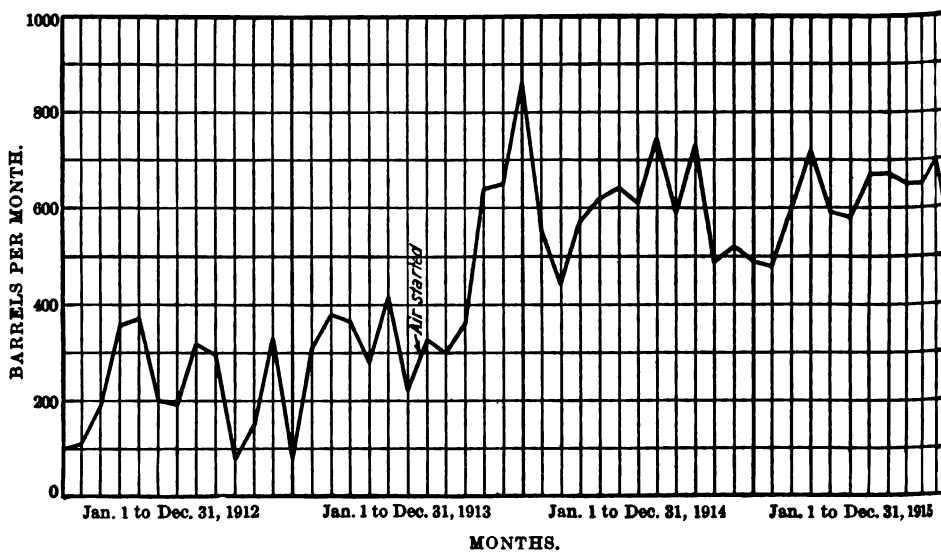


FIGURE 20.—Production curve of property No. 6, Table 4. It took three months to influence production. The sand is fairly tight and the wells had been gas pumped for many years. Almost no decline was shown after compressed air had been used more than two years.

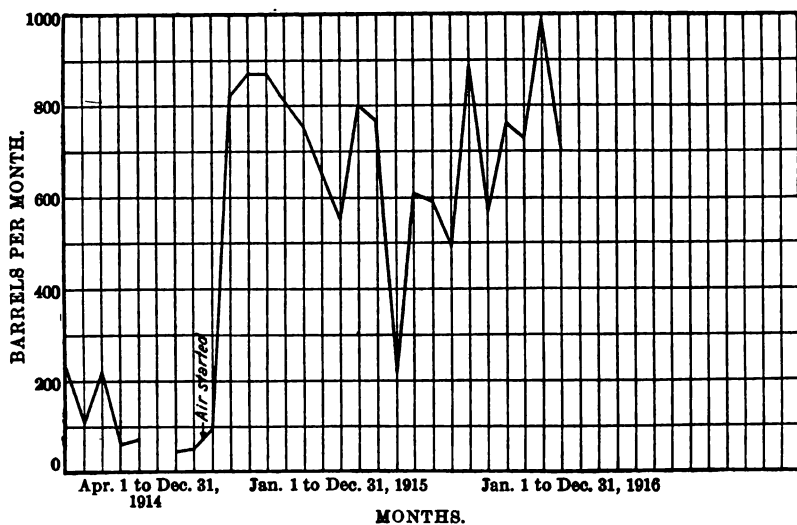


FIGURE 21.—Production curve of property No. 14, Table 4. Shows a rapid and large increase in production. Note increase for the last nine months.

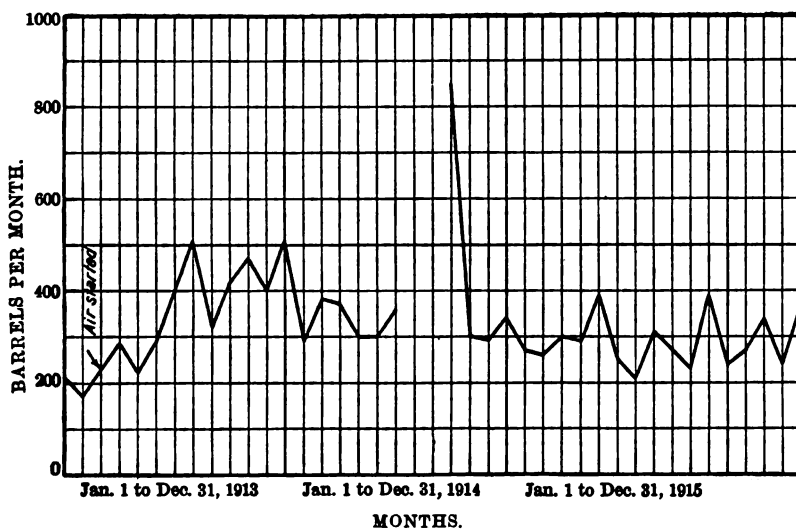


FIGURE 22.—Production curve of property No. 8, Table 4. The increase of production has been comparatively small, but has been maintained with little decline.

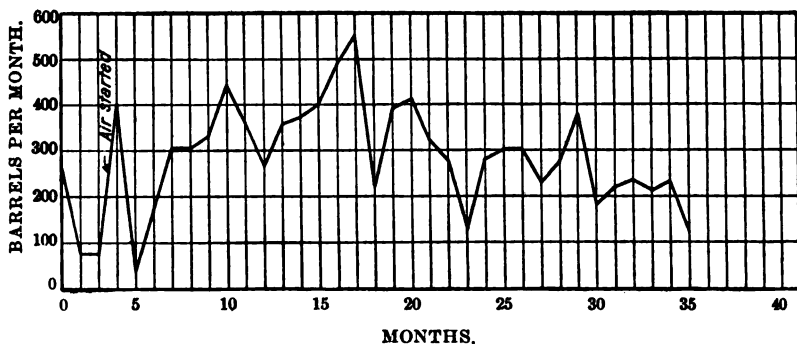


FIGURE 23.—Production curve of property No. 11, Table 4. Oil sand is tight, requiring pressure of 240 pounds. It took four months to increase yield and the increase has been only moderate.

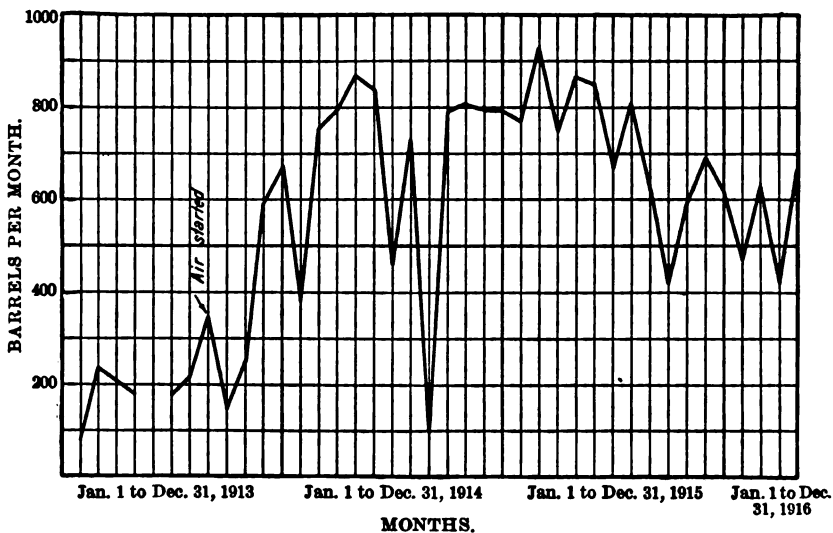


FIGURE 24.—Production curve of property No. 7, Table 4. The property had been gas pumped six years and the first wells were drilled in 1861.

EFFECTS OF THE PROCESS ON RECOVERY.

On some properties using the process no appreciable increases in production have been reported, although even the majority of these have shown some increase. On at least two properties the production has been increased ninefold, and still larger increases have been reported, but the writer did not find opportunity to substantiate them. The records of 32 properties, including several where the process was only partly successful, give an average increase of three and one-half times the production at the time the process was started, this increase being sustained for periods of several months or more. The productions of 14 representative properties are shown in figures 11 to 24.

As the operating expenses usually are not increased proportionately with the oil production, profits show a relatively greater increase than production. On some of the properties where the process was installed the yields had so closely approached the economic minimum that producing was profitable only during the periods of most favorable market conditions. Favorable results from the process have kept many wells from being abandoned, and caused the rejuvenation of old wells which had been abandoned.

It is not possible to estimate what the total increase in recovery will be because the beneficial limits of the process have not been reached on any property, nor do we know what improvements may be made in future. The benefits may terminate abruptly, or, as is more probable, there may be a gradual decline similar to a normal well decline, as is suggested by some of the production curves. On the whole the future is more hopeful than the present results indicate because the process is so new that there are many possibilities of increasing its efficiency.

Although the average increase has been about three and one-half times, the actual productions ordinarily remain very small compared with those obtained in the early lives of the wells, for previous to the use of the process productions had dropped to very low rates, being on most properties less than one-fourth barrel per well daily. While the increases are relatively important, they would have to be maintained for long periods before the percentage of increase in total recovery would be large. For example, the property represented by figure 11 marketed a total of 191,045.65 barrels of oil during the period of 13½ years covered by the production curve, which, however, does not include the first 8 years of the life of the property. Of this total about 35,000 barrels, or 18½ per cent, is attributed to the increase caused by the process during the 5 years it has been used (see fig. 11), but it must be noted that not only is the production increased but the abandonment of small wells, otherwise unprofitable, is prevented, and that the whole property is not

equipped with the process. In order to double the natural production since 1903 the present rate would have to be maintained for about 20 years longer, and to double the production for the entire life of the property would require a length of time practically beyond consideration. The production curve of this property and of most of the others where the process has been used long shows a tendency to decline, which if unchecked will make a doubling of total recovery not to be hoped for on the average property in the Appalachian field; and, in fact, it is far more likely that if the future does not show greater efficiency the total increased recovery on the average property can not reach 50 per cent. Even these indefinite estimates are based on the assumption that the benefits of the process will continue for long periods, for which there is no adequate proof at the present time, but they serve to show the limiting factors as the process has so far been conducted and that if the recovery to date by ordinary means actually has been but a small proportion of the underground supplies, as is indicated by the data submitted previously, production would have to be continued almost indefinitely before even half of the unrecovered oil could be extracted. The indications are that the process as now conducted is far from perfection, but nevertheless it will play an important part in prolonging the supply of oil.

In the laboratory experiments the ultimate recoveries by the continued passage of air through the sand were large, especially with the light eastern oils, but much of the oil extracted toward the end of an experiment required such large volumes of air that similar recovery in the field would obviously be impracticable. However, if the recoveries from the fields by the usual methods have been no greater than indicated by the facts submitted previously, a wide margin still seems to lie within the practical limits of recovery, provided the efficiency in the field can be brought reasonably near that in the experiments. Judging from the experimental data, it may be possible to prolong production at gradually diminishing rates for many years if economic conditions permit.

DISCUSSION OF THE PRODUCTION CURVES.

The production curves on properties employing the process, shown in figures 11 to 24, are based upon authentic records of oil shipments. The sharp irregularities in production between months are caused largely by the time of the month shipments were made, and are due only in a less degree to the variations in the well productions. During the period August 1, 1914, to October 1, 1914, production was arbitrarily curtailed by the pipe-line companies who refused to ship the full capacity of the wells because of glutted market conditions.

The curves are typical of their several types, and are fairly representative of the properties where the process has been so far successful that its use has been continued.

Especial interest is attached to the curves covering periods of two years and more. The longest period is five years, shown in figure 11. Where the records cover a sufficiently long period to show the nature of the curve, it may be observed that maximum production is usually reached 6 to 18 months after the process has started, after which there is usually a gradual decline. Figures 11, 14, 15, 18, 19, 22, and 24 are of this character, while figures 16, 20, and 21 show little or no decline, and in figure 16 the maximum production has not been passed, although the process has been in use three years. These records are too few to permit general conclusions, and it is possible that the tendencies noted in these records will not be substantiated when more complete data are available in later years. Under natural conditions, the operator has little control over the factors of oil production, but in the Smith-Dunn process some of the conditions are under his control, and consequently there is more chance for him to improve the process, which will considerably affect the productions of the wells. Originally there was in the sand a limited amount of gas which expelled the oil, and was finally exhausted, but in the Smith-Dunn process the expulsive force is being put into the oil sand continuously, and may be increased or decreased both in volume and pressure at the will of the operator. For this reason it can not be presumed without evidence that a well will decline under this process in the same way as under natural conditions. Production may continue for a period and then end abruptly, or, as is more likely, it will gradually decline unless checked by changes in the way of operating the process.

EFFECTS OF THE AIR ON THE QUALITY OF THE OIL.

Some apprehension has been expressed that the air pumped into the sand would unfavorably affect the quality of the oil, but repeated inquiries disclosed only one complaint by the producers on this account, and the general opinion held is that the oil is livelier, of better quality, and is even claimed to be lighter than formerly. Analyses of oils affected by the air do not show any noticeably unfavorable alterations in the oils.

The apprehension is doubtless caused by observing the deterioration of oil when exposed at the surface. Deterioration is caused principally by the lighter parts of the oil evaporating when exposed to the atmosphere, but this would also occur were the atmosphere composed of natural gas instead of air. With the underground conditions the effect of forcing dry gas through the sand would be the same as forcing the air through the sand, except that there is some chemical

reaction between the oxygen in the air and the oil, there being a tendency to oxidize the unsaturated hydrocarbons. The statement that the oil has been lightened has been made repeatedly and upon good authority, but the writer was unable to establish this definitely on any single property because he had no records of the gravity of the oil at the time the process was started.

No increased troubles from the deposition of paraffin in the sands was reported by the operators using the air on their properties, whereas in many instances it has been reported that the increased pressures from the air have forced much waxy material from the wells. If there is a tendency for the expanding air to cause refrigeration and deposition of paraffin, as feared by some oil men, it appears to be counteracted by the increased pressures which force the paraffin out instead of letting it accumulate in the pores of the sands as formerly under the weak gas pressures. The presence of the air under pressure in the sand allows the use of methods for removing the paraffin from the sand about the hole that could not be used before, as it will force out the waxes as soon as melted, instead of letting them seal up the sand, as would happen were there not a strong gas pressure in the sand.

EFFECTS OF THE AIR ON THE WATER.

The forcing of air through the sand usually increases the volume of water produced with the oil, but this increase is reported to be proportionate to the increase of oil, so that the ratio of oil and water produced remains approximately the same. In some wells the volume of water made fluctuates, and instances have been reported where a well will make water almost exclusively for a while, to be followed by a period when little water accompanies the oil. Complaint seldom has been made by the users of the process because of the increase in water, as it has been proportionate to the increase in oil.

The only serious complaint made was where the process was used near Lima, Ohio, in wells producing from the Trenton limestone. Producers in this district report that normally 30 to 40 barrels of water accompany each barrel of oil produced by the ordinary methods. When the air was forced through the sand the volume of water became so great in many wells that the users became discouraged and stopped the process. Whether the process will affect other fields similarly, where large quantities of water are present, is not known, because the character of the oil-producing rock, a porous limestone, is not the same as for oil sands.

A number of users of the process have reported that the water corrodes the tubing and pumping equipment more than formerly. The following analysis of a sediment produced with the oil indicates

that there is some basis for complaint, for presumably the iron in this sediment is derived from the corroded equipment in the well:

Analysis of sediment interfering with pumping apparatus on oil property near Oil City, Pa.

[Analysis by W. C. Cope, Bureau of Mines.]

Constituent.	Original.	Corrected.
Moisture -----per cent---	4.55	4.51
Oil -----do-----	17.32	17.21
Sodium chloride -----do-----	5.52	5.48
Calcium sulphate -----do-----	1.70	1.69
Calcium carbonate -----do-----	5.63	5.59
Silica -----do-----	1.21	1.20
Carbonaceous material -----do-----	1.30	1.29
Iron rust ^a -----do-----	63.57	63.03
	100.80	100.00
 Ferric oxide ^a -----	 55.41	 54.95
Carbon dioxide -----	1.21	1.20
Water -----	6.95	6.88
	63.57	63.03

When the water is aerated by the air passing through the sand its power for corrosion is increased. The unfavorable effect will depend largely on the character of the water, and if it has corroded the equipment previously, the trouble may be aggravated, but if it has not, it is not likely that the air will cause trouble. The cost of producing oil has been increased on certain properties because of this trouble, principally by the formation of a sediment which gets into the pumps and cuts the cups, but relatively the effect has not been serious.

PUMPING TROUBLES OFTEN INCREASED BY USING THE PROCESS.

Not only does the air sometimes increase the formation of sediments by the corrosion of the iron in the well, but it may bring more floating sand and other sediments into the well which will increase pump troubles and make it necessary to pull the wells more frequently than before. On many properties the additional trouble is negligible, whereas on others it has considerably increased the expense of operating. Less trouble has been experienced from hard, tight sands, and the previous condition of the well has proved to be a very important factor, for it has been generally noted that those operators who clean their wells with unusual thoroughness have had less trouble than their neighbors. Pump troubles are reported to diminish with time on those properties where the process has been in use long enough.

^a A hydrated ferric oxide containing some carbonate.

Probably pump troubles have been caused not only by the increase of sediments but by poor pumping equipment inadequate to handle the increased production. On many properties where the process has been employed the equipment had been allowed to deteriorate and the wells had not been kept in condition because the yield had become so small that the producer could not afford to make any but essential repairs or replacements of equipment.

EFFECTS OF THE AIR ON QUANTITY AND QUALITY OF GAS.

In all instances reported, the volume of the gas has been increased considerably. On many properties when the compressors were first installed there was not sufficient gas to run the plant more than a short period during each day, but as the air was forced into the sand the quantity of the gas increased so that soon the plant could be run to its full capacity. On a number of properties insufficient gas formerly had made it necessary to purchase gas or gasoline for fuel to furnish power, and on one property coal was burned under boilers for pumping the wells. Some of these properties previously short of gas now have an excess that is being burned in flambeaus.

The increase in quantity is largely due to the air which passes through the sand and becomes mixed with the gas, but there must also be an actual increase in the quantity of petroleum gases, as the air-gas mixture supplies more power than the gas formerly produced.

The compositions of the air-gas mixtures vary in the percentages of air, of gasoline vapors, and of the other petroleum gases. The quantity of gasoline vapor is roughly proportionate to the percentage of natural gas. Following are analyses of some air-gas mixtures:

Results of analyses of air-gas mixtures.

Constituent.	No. 7841 ^a .	No. 7846 ^b .	No. 7844 ^c .	No. 8433 ^d .	No. 8436 ^e .
Carbon dioxide (CO ₂)..... per cent.	1.07	1.20	0.70	4.60	7.00
Oxygen (O ₂)..... do.	19.40	4.30	16.80	12.90	.50
Nitrogen (N ₂)..... do.	76.69	73.70	78.00	75.60	2.60
Methane (CH ₄)..... do.					64.30
Ethane (C ₂ H ₆)..... do.				2.50	25.70
Propane (C ₃ H ₈)..... do.		16.40		4.40	
Butane (C ₄ H ₁₀)..... do.	2.84	4.40	4.50		
Gasoline—pints per 1,000 cubic feet.....	1.44	13.90	3.40		

^a Air-gas from property No. 6 (Table 4); very lean, burns without visible flame; is not being used.

^b Air-gas from property No. 31 (Table 4); fairly rich, being used in gas engine.

^c Air-gas from property No. 5 (Table 4); being used in gas engine.

^d Air-gas from property No. 11 (Table 4); lean gas, being used in gas engine. Gasoline not determined.

^e Gas from a property near Warner, Ohio, hardly affected by the air. Gasoline not determined.

An operator in the Bradford field reports that the gas from wells 500, 1,500, and 2,150 feet away from an air well showed 76, 26, and 10 per cent of air, respectively. (See fig. 32, p. 115.)

At times the air-gas mixture is so lean it will not burn without the addition of more gas. Evidently the composition of the air-gas

fluctuates when the process is first started, for it has been reported that in some instances trouble was experienced in regulating the fuel mixture in the gas engines, though this may be caused by drawing from several wells gas of different composition that does not get well mixed in the lines. After the process has been in use for a while the air gas seems to be more constant in composition and less trouble is experienced from this cause. It would be expected that the continued passage of air through the sand would remove the petroleum gases, so that eventually the gas would become very lean. Evidence from experience is not yet clear on this point, for properties where the process has been in use longest do not always report trouble of this character, whereas some other operators claim that the gas became lean not long after the process was started. It is believed that much of the lean gas is caused by air by-passing or blowing through, and if the operators would exercise more care in regulating the passage of the air through the sand, less trouble would be experienced with lean gas. There is also some evidence that using too high pressure may cause lean gas without adequate benefits from the increase in oil production. The air-gas from the different wells will not be the same in composition, and, if necessary, the gas from some wells can be cut out if too lean. Lean gas ordinarily may be considered as evidence of inefficient expulsion, for if the air were doing its proper quota of work it is hardly likely that it would come through the sand too lean to use.

The dilution of the gas makes it necessary to adjust the air and the gas intakes on the gas engines. The gas intakes must be enlarged in proportion as the gas gets lean, and the air intake must be reduced correspondingly. At times the fuel mixture will hardly need the addition of any air. The fuel value of the air-gas is less than that of natural gas, and consequently more of the air-gas must be used in the gas engine. As is shown by the analyses on page 80, there is apt to be an abnormal proportion of nitrogen in the air-gas, so that the fuel value is reduced to less than that of a proper mixture of normal air and gas, and thus the power of the gas engine is diminished by the presence of this excess of inert nitrogen, and the actual power delivery of the plant may be considerably reduced below the rated horsepower, which is one reason why a plant should be installed with reserve power.

The excess of nitrogen in the air-gas is probably due to the extraction of oxygen from the air during its passage through the sand rather than to the picking up of nitrogen. The cause for the change of composition of the air is probably due in most part to chemical reactions between the oxygen and the oil, or with other substances underground, but it may also be partly caused by a greater per-

centage of oxygen being absorbed in the oil when the air is passed through the sand, as suggested by the coefficients of absorption for oxygen and nitrogen in petroleum as given on pages 11 to 13. If this is the principal cause, it shows that vast quantities of oil must be present underground to account for the change in the composition of the large quantities of air being forced through the sands.

EFFECT ON MAKING GASOLINE FROM THE GAS.

The increasing use of the Smith-Dunn process has occasioned inquiries regarding its effect on the making of gasoline from natural gas. So far as it has been used to the present time, the process has diminished the extraction of gasoline. Although the volume of gas is increased, it is apt to be too lean for profitable making of gasoline by compression. A few plants are condensing gasoline from the air-gas by compression, but the majority of the gasoline plants were discontinued where they depended upon the gas from the properties installing the Smith-Dunn process.

As the gas is diluted with air, higher pressures are necessary; also a greater volume must be put through the compressors to obtain the same yield of gasoline; and these facts seriously affect the manufacture of gasoline from such gas. The analyses show, however, that some of the air-gas is still rich enough to make compression profitable, and it has been shown in Bulletin 88^a that many compression plants have used gas with high air contents, some containing as much as 40 per cent of air. By adding an expansion engine to the equipment and reducing the temperatures, probably it will often be possible to continue to condense the gasoline at the pressures used previously.

According to Burrell, the presence of air will probably affect the extraction of gasoline by absorption methods to a much smaller degree than by compression methods, and it is likely that gases rendered too lean to be treated profitably by compression may be suitable for the absorption process when it is perfected for use in small plants.

PRECAUTIONS IN USING THE AIR-GAS.

The analyses of gas from producing wells on properties using the Smith-Dunn process show that it is a mixture of natural gas, gasoline vapors, and air in varying proportions. Sometimes the mixture is such that it will burn or explode upon ignition without the addition of more air, and occasionally it is too lean to be inflammable. Ordinarily, the air-gas is too rich to be explosive, but Burrell^b has

^a Burrell, G. A., Selbert, F. M., Oberfell, G. G., The condensation of gasoline from natural gas: Bull. 88, Bureau of Mines, 1915, p. 68.

^b Burrell, G. A., Selbert, F. M., and Oberfell, G. G., work cited, p. 97.

shown that the limits of explosibility for natural gas range from about 3.5 per cent to 9.5 per cent of wet gas. The mixture of air and gas is more dangerous than pure unmixed natural gas, and this fact should be kept continually in mind in all operations on a property where the process is being used. In spite of the obvious dangers there have been surprisingly few serious accidents.

The air-gas is commonly used as a source of power in the compressor plants, is sometimes used for domestic lighting and heating on the leases, and at a few plants is used for making gasoline by compression. Burrell^a has shown that frequently considerable air is also mixed with the gas on properties being vacuum pumped, sometimes 40 per cent of the mixture being air, but the writer has heard of no explosions from this cause in compressors for condensing gasoline. These mixtures are, however, much richer than the average from wells using the Smith-Dunn process. An air-gas within the explosive limits will in all probability be too lean to make gasoline by compression, but the presence of air in the gas should be taken into account and factors of safety adopted accordingly.

A number of reports have been made that the air-gas has been ignited and the flame traveled back in the pipes to the well. Mr. I. L. Dunn states that this has happened several times in his experience, sometimes purposely, but without serious consequences, the pipe and the well not being damaged. One accident was caused by attempting to start an engine with compressed air-gas, which was ignited and reached the charging tank through a leaking valve, blowing it up with great violence. Backfiring into the gas line can be prevented by inserting at the proper point a section of larger pipe filled with small iron tubes or rods that will smother flames by cooling, much as the gauze in an oil safety lamp prevents the mine gases from being ignited by the flame of the lamp.

Occasionally oil will flow from a well by the compressed air. This is reported to have been the cause of one accident. The oil flowed into the gas line and reached the cylinder of the gas engine. By installing a trap in the gas line through which all the gas must pass before reaching the engine this can be prevented.

Apprehension has been expressed of the air-gas in the oil sand becoming ignited and exploding. This does not seem to be a possibility, as the oil sand itself would tend to smother the flame, so that the air-gas in the pores of the sand can not be exploded.

Precautionary measures applicable to properties using the Smith-Dunn process are given in Bulletin 88.^b

^a Work cited, p. 66.

^b Burrell, G. A., Seibert, F. M., and Oberfell, G. C., The condensation of gasoline from natural gas: Bureau of Mines, 1915, pp. 67-68.

COST OF USING THE PROCESS.

In the following discussion on the cost of using the Smith-Dunn process only the additional expenses caused by its use are considered. These extra costs depend on so many variable factors that it is not advisable to make detailed statements. An endeavor is made, however, to give in a general way the relative expense of installing a plant and the increase in operating expense, as well as to outline the factors influencing the increased costs. Royalties or charges to be paid for patent rights are not taken into account.

COST OF INSTALLING.

At least 80 per cent of the first cost in installing the process is for machinery and other equipment. Under the abnormal conditions prevailing at present the prices of such materials are so unstable that no detailed estimates of cost would be of value. Moreover, the local conditions on each property are so diverse that only the broadest statements would be justified, even were the prices of materials fairly stable.

For equipping a property to use the process there are necessary:

1. A compressor plant, including gas engine, compressor, housing, and accessories.
2. Pipe lines for distributing the compressed air and for gathering air-gas for fuel purposes.
3. The preparation of air wells and the putting of pumping wells and their equipment in proper condition.

The factors governing the size and type of compressor plant have been given previously, and it has been shown that less than 1 to nearly 5 horsepower may be required per well (air and pumping wells), the average being 1.83 horsepower per well. The compressor plants used have ranged in size from 20 to 185 horsepower, though few plants are more than 100 horsepower. Of the equipment, about 70 per cent goes into the compressor plant (including housing and installation), the other 30 per cent being for the pipe lines. The costs of preparing the wells and pumping equipment are not large if the wells and the equipment are in good condition. The cost of installing the process will depend largely on the equipment already in use on the property. If it has been gas pumped, or if a compressor for condensing gasoline has been used, much of the same equipment can be employed in the Smith-Dunn process, or, if not, the cost may be partly compensated by the value of the equipment replaced. The gas engines can often be used for running the compressors, and sometimes the vacuum pumps can be altered and made into compressors if they are of the proper type and size. If the property has been gas pumped the suction lines can be used for air-gas lines, or the

pipe can be used for conveying air to the air wells. The air lines have 2-inch to 4-inch mains with 1-inch to 2-inch laterals to the air wells. One-third to one-sixth of the pumping wells are changed into air wells. The items of cost for the air wells may be gained from the description of air wells given elsewhere. In general, the cost is not great and will be largely compensated by the pumping equipment replaced.

The presence of the compressed air on the property supplies a source of power readily distributed over the lease and permits the use of different pumping equipment which may make a difference in the first cost.

Plants installed before the present abnormal conditions arose cost \$50 to \$150 per well, the average being about \$100 per well. Figured in another way, the cost was \$30 to \$50 per rated horsepower used.

COSTS OF OPERATING.

Inquiries as to the cost of operating properties by the Smith-Dunn process usually brought out the statement that the cost had been increased a little, but not much. Sometimes it was stated that the cost had been increased 25 to 50 per cent, and in one or two instances it was claimed that the expense had been doubled. It was claimed that the expense has been lessened on a few properties by using the compressed air for pumping the oil, the cost being less than when the property was gas pumped.

The items that may increase the cost of operating are: Costs of running the compressor plant, including extra labor where necessary, fuel and water supply, lubricants, repairs and replacements, depreciation and interest on the investment; costs due to the added expense of handling more fluid, and often the increased troubles at the pumping wells due to the sediments brought in by the air. Of these, the chief items of expense are ordinarily the extra labor and the increased pumping troubles.

The extra labor cost depends largely on whether or not the operator chooses to have men stationed at the compressor plants continuously. In general, only one man is used at the compressor plant, it being allowed to run during the night without attendance. Experience has shown that on the ordinary property the liability of preventable damage is not such as to warrant the extra cost of keeping a man at the plant both day and night, where systems are installed for automatic lubrication during periods of 12 hours or more and for stopping the engines should anything happen to the water supply. By these means a saving of \$70 to \$90 a month for an extra mechanic is effected. Lubrication, repairs, and replacements are not often important items of cost in an efficient plant. It

is not often necessary to use other fuel than the natural supply of air-gas, and the only charge which might be made against this item would be the selling value of what gasoline might be recovered from the gas. The cost of water has been nominal in the established plants, and will be elsewhere except in some of the western oil fields, where water may be difficult to obtain. The actual depreciation is not great, but owing to the fact that it is not known how long the production will be benefited, and consequently how long the plant will be in use, a high rate of depreciation should be adopted. The additional fluid which must be handled increases the total operating cost for the property, but decreases the cost per barrel.

The most variable factor in the cost of operating, however, is the trouble in the pumping wells caused by the sediments brought in by the air. On a number of properties the extra expense from this cause has been large, whereas on others it has been nominal. As stated before, pumping trouble is largely due to whether or not the wells have been thoroughly cleaned, and adjoining properties may show entirely different results. Experience on the older properties encourages the belief that usually this trouble will decrease with time.

FIELDS WHERE SMITH-DUNN PROCESS HAS BEEN USED.

Outside of the district in Ohio where the Smith-Dunn process was started, it has been used on several properties near Oil City and Bradford, Pa., also five plants were in use in the Trenton limestone pools of Ohio and Indiana. In southern Kansas it was used in one pool, and in Oklahoma in two pools in the Bartlesville sand, one being where the wells were small and shallow, the other being where the wells were comparatively deep and had been unusually prolific, and still produced large quantities of oil. In California it was experimented with in a small way in a shallow pool producing light oil, the condition being not like those found in most California oil fields.

CONDITIONS UNDER WHICH PROCESS HAS BEEN USED.

To date the process has been applied almost exclusively to wells that had declined to very small productions, the daily yield in many instances being less than one-fifth of a barrel and near the minimum limit of profitable operation. Some of the properties were drilled early in the history of oil producing, some of them dating from the period of 1860-70, and many of the properties had been gas pumped. The depths of the wells range from less than 100 to more than 2,000 feet, and the sands range from fine to pebbly, thick or thin.

The oil is of paraffin base, and, with the exception of some of the oil in Oklahoma, of very light gravity, being 35° to 50° B.

The greatest successes have been obtained in the First Cow Run sand of southeastern Ohio and the Big Lime sand in the district near Woodsfield, Ohio. The First Cow Run sand is usually of coarse, open texture, the wells in it are shallow, and the original pressures were low, but the initial productions were often high, some of the wells starting at several hundred barrels daily. Production has been long sustained, and some of the oldest producing wells in the country obtain their oil from this sand. The Cow Run sand generally occurs in narrow, sinuous "streaks," or as small lenses inclosed in beds of shale.^a In the Woodsfield district, the Big Lime sand^b is a true sand, being found in lenses embedded in the lime, and often of small extent, the whole pool sometimes supporting but a few wells. In both the Cow Run sand and the Big Lime sands, the conditions are unusually favorable for quick and decisive results, the sand being of fairly coarse and open texture, while the pools are small and narrow so that the effect of the air has been confined to a small area. The geologic conditions of these districts are sufficiently covered in the publications of the various State geological surveys, and of the United States Geological Survey.

The columnar section, shown in figure 25, from Bulletin 621^c of the United States Geological Survey, shows the different sands in the district along the Ohio River where the Smith-Dunn process has been used longest and most extensively. The process has been applied to nearly every sand shown. Outside of this district the process has been used in the Rosenberry sand near Emlenton, Pa., the Third Venango sand near Oil City, Pa., the Bradford sand near Bradford, Pa., the Trenton limestone near Lima, Ohio, and Geneva, Ind., and the Bartlesville sand in the Nowata and Boston pools of Oklahoma, and the Sespe sands in Ventura County, Cal.

FAILURES OF THE PROCESS.

Universal and unqualified success is too much to be expected from any process like the Smith-Dunn, especially when new and unperfected. A number of cases have been reported where little or no increase was gained. Failures were caused in the Trenton limestone pools of Ohio and Indiana by the increase of water and the erratic and uncontrollable movements of the air underground. On a few properties the use of air was discontinued and natural gas substituted,

^a Bownocker, J. A., Oil and gas: Bull. 1, Ohio Geol. Survey, 4th ser., 1908, pp. 164-172.

^b Condit, D. D., Structure of the Berea oil sand in the Woodsfield Quadrangle: U. S. Geol. Survey Bull. 621, 1916, p. 242.

^c Condit, D. D., Structure of the Berea oil sand in the Woodsfield Quadrangle, 1916, p. 240.

not because the increases in production were unsatisfactory, but because the gas from the properties was being used for domestic purposes, or the operators feared it would get too lean.

Undoubtedly many of the failures were preventable and were not due to inherent faults in the process. In at least one case failure was turned into success when the property changed management, and it is likely that other failures could be made successful with proper equipment and experienced application of the process. But until it has actually been demonstrated that a failure was preventable, it must be set down against the process. From inquiries through the fields it is thought that the failures will be less than 20 per cent of the total number of times the process has been used.

From what could be learned of local conditions, failures to appreciably increase production might be traced to some of the following causes: One property never had been profitably productive; on several properties the compressor plants were probably too small, for in one case enlarging the plant made the process successful; in at least one instance the waste of air through old wells, and wells improperly cased, probably caused failure; trying to force the air into too few air wells has been a probable cause, and expecting results too soon has been another (the reader is

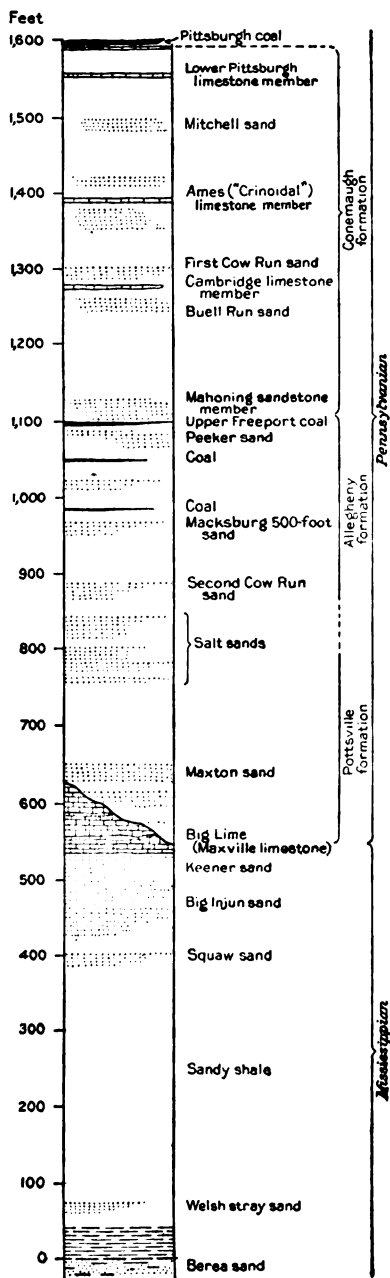


FIGURE 25.—Generalized section of the oil sands in the district around Marietta, Ohio. After Condit.

referred to the production curves as evidence that success may not come until after the air has been in use several months; by-passing

and blowing through are reported as causes on a number of properties. In some instances failure can not be traced to any probable cause, and at present must be set down as unexplainable.

A popular opinion has been that the process will fail when applied to tight sands or to deep wells. There are hardly sufficient data to disprove either contention. Up to a depth of 2,000 feet there has been no evidence that the process will not be successful in deep wells where other conditions are favorable. The popular opinion of failure in tight sand has been gained from the facts that a few failures are reported from the 500-foot sand at Macksburg, Ohio, which is said to be a tight sand, and that most of the conspicuous successes have been in the coarse First Cow Run sand and the Big Lime sand near Woodsfield, Ohio. The tight sand requires greater pressure and a longer time to get results, but so far the failure of the tight sands is by no means conclusive. Two properties report using pressures up to 300 pounds; on one the increase is small, but on the other the increase is reported to be three and one-half times. Figures 18, 19, and 23 represent properties where the sand is medium or fine grained, and the pressures used are, respectively, 160 pounds, 110 pounds, and 240 pounds. The wells represented by figure 19 are producing from the 500-foot sand at Macksburg.

POSSIBILITIES OF EMPLOYING THE PROCESS IN OTHER FIELDS.

Despite the diversities of conditions in the various oil fields of the United States, the recovery of oil has seemingly been low everywhere, regardless of the local conditions, or original pressures, depths of well, or of the character of the oil and the character and texture of the oil sands. The cause of decline in all oil fields can be traced to the depletion of the natural gas accompanying the oil; therefore it seems logical that in other fields forcing air through the sand would increase production the same as in fields where the process has been used, although local conditions will determine whether or not it can be used profitably.

The conditions in the Appalachian, Illinois, and Mid-Continent fields are so essentially alike that it hardly seems possible that the process can fail in the other districts if successful in one, but when extended to fields like those of California, Texas, and Louisiana the conditions are so different that it is hardly safe to forecast results, though the experiments with loose sands and California oils gave proportionately more favorable results than the experiments with light eastern oils. For one thing the building up of pressure is likely to cause loose sand to come into the wells, which may neutralize the benefits.

It is interesting to note that in the use of compressed air in California for pumping wells by the air-lift system, Arnold and Garfias* have reported that in time the yields from wells so operated show an undoubted decline, whereas wells near by not operated by air have been observed to show an increase. These facts suggest that some of the air from the air lift entered the sand and moved the oil away from the hole toward other wells where air was not being used.

The use of the Smith-Dunn process has been practically confined to old wells which had nearly ceased producing. It would be of interest to know whether the process can be used profitably in wells that have not reached such low productions. It was applied with some favorable results to one property in Oklahoma where the yields were still high, but the conditions were such as to make it difficult to tell whether the use of the process had been sufficiently beneficial to make it worth while. In the Cushing field, in Oklahoma, the accidental admission to an oil sand of high-pressure gas from a deeper stratum temporarily greatly increased the flow of a well which previously yielded about 50 barrels daily. This lends encouragement to the view that the Smith-Dunn process can be used profitably in the early life of a well to stimulate production. This process was tried on a small scale in Ventura County, Cal., the air being forced into a well on the edge of a small and very shallow field for several months, but no appreciable increase in the yields of oil or gas was reported. The oil sand was fairly compact for a California oil sand and the oil had a gravity of 30° B. Why the air did not affect the gas yield can not be explained.

USING NATURAL GAS FOR INCREASING RECOVERY OF OIL.

In using the Smith-Dunn process, results with natural gas seemingly should be as effective in forcing oil from the sand as the use of compressed air, and in addition presents some advantages as compared with using air. The principal advantages offered by the use of natural gas are: The gas recovered from the pumping wells would not be diluted with air and the fuel value decreased; dangerous mixtures of air and gas could not be formed; on properties where natural gas was available in sufficient volume and under high enough pressure no compressor plant would be needed; at times the exhaust gases from gasoline compressor plants could be employed without further compression.

The physical effects of air and natural gas in the sand are much the same. More of the natural gas will go into solution under the same conditions, but whether this fact would prove of importance

* Arnold, Ralph, and Garfias, V. R., *Methods of oil recovery in California*: Tech. Paper 70, Bureau of Mines, 1914, p. 21.

in practical operations is not known. Apparently the air has not affected the oil unfavorably; and, so far as the writer knows, there would be little choice between air and natural gas from this cause. Theoretically air or any other gas would carry just as much gasoline vapor as natural gas, and where it is hoped to recharge dry natural gas by passing it through the oil sand probably no better effects will be gained than with air.

The effect on producing oil wells of admitting natural gas into the oil sand, accidentally or otherwise, has been noted many times in the oil fields. I. L. Dunn states that it was observing such a case that led him to develop the process of using compressed air. An instance in the Cushing field, where the flow of a comparatively new well was greatly increased by natural gas from a deeper sand getting into the oil sand has already been mentioned. It has been reported that gas under natural pressures has been used at various times to stimulate oil flows, and it is also reported that the exhaust gas from gasoline compression plants has been returned to the oil sand, principally with the idea of recharging it with gasoline vapors.

The choice between natural gas and air will usually be decided in favor of the latter because the natural gas will not be available, or only at costs relatively prohibitive. The operating method will be approximately the same, and what has been said about operating with air will apply to the use of natural gas. If the natural gas is not already under pressure, it will have to be put through a compressor plant in the same way as air. By carefully gathering the return gas and putting it through the compressor again, it may be circulated in a closed circuit except for the wastage underground and on the surface, and the quantity used for fuel. By careful operation the wastage should not be large. In the early life of an oil field, while much natural gas is still being produced with the oil, it might be profitable to save the gas and put it back into the oil sand, by this means both accelerating and increasing the recovery of the oil.

INCREASING RECOVERY OF OIL BY WATER DISPLACEMENT.

GENERAL STATEMENT.

Water is practically considered the only available fluid that might be forced through the oil sands to increase recovery, but water—especially fresh water—has usually been considered the arch enemy of the oil man, and the necessity for excluding it from the productive strata has caused the use of casing, packers, cement, and other materials, which have greatly added to the expense of completing an oil well. The general recognition by both practical and technical men of the harm that may result from the entrance of water into the oil sands has caused the passing in all oil-producing States of stringent laws regulating the abandonment of wells and the exclusion of water from the oil sands. The displacement of oil by “flooding” the sand with water has been against the experience and the judgment of the oil men.

Observations that water will displace much of the oil from laboratory specimens of oil sands and that “flooding” often will stimulate yields of oil wells, at least temporarily, have led to much speculation regarding the possibilities of increasing the recovery of oil by this means. These facts were observed early in the history of oil production in the first fields developed in Pennsylvania, and since that time flooding, usually on a limited scale, has taken place in many other fields and under a great variety of conditions.

Often the first intimation in a producing well of an approaching flood is a sudden increase in oil yield without apparent cause. Within a short time the yield may increase many fold, this increase being maintained for periods of several days to several months, and even for many years, as in the Bradford field. The yield, after increasing, is not apt to decline until the water makes its appearance, then the oil is usually quickly and completely cut off by the water and the well becomes valueless. The phenomena of flooding are so familiar to oil men that they regard a sudden increase of oil in an old well, without apparent cause, with suspicion. Frequently, however, the water enters a well without increasing the yield of oil, and, in California, water has been known to enter a well and almost cut off the production in a few hours. Ordinarily, the benefits, if any, are so shortlived and so much less than could have been reasonably expected from ordinary producing methods that flooding in nearly all fields is regarded as a deplorable calamity.

In nearly every instance where flooding has occurred it has been of accidental origin and has not been started intentionally for the purpose of increasing recovery. The causes can usually be traced to defective wells, usually abandoned, or to the encroachment of water rising from the lower levels of the productive formation. Ordinarily, the producers attempt to stop or to localize flooding as soon as discovered. Sometimes a whole field is drowned out, but more often the flooding is stopped after affecting a small number of wells, because the offending wells have been repaired or the sand has been practically sealed up with cavings, or the movements of oil and water have virtually ceased because of the depletion of the water supply. However, in nearly every field will be found some wells that have been drowned out, not by water entering the sand from the well itself, but by water coming through the producing formation. At times the producers have endeavored to take advantage of flooding by drilling in advance of the water or by trying to control the movements of the water by admitting water into wells situated at strategic points. The comparatively few successful attempts have as a rule caused injury to other producers in the same field.

Flooding is excellently described by Carll^a and other early writers, who note the effects of flooding at Pithole and in other early fields in Pennsylvania. Carll outlined the principles of flooding and came to the conclusion that terminating the life of a nearly exhausted well by displacing the remaining oil with water was sound in theory, but because of the clashing interests in a field, the difficulties of controlling the movements of the water, and the dangers of trapping oil it could seldom be applied advantageously. Practically the same views have been held by Huntley,^b Johnson,^c and others, who maintain that the fault lies not in the theory but in the attempts to concentrate the oil by flooding without sufficient data as to underground conditions. Among the oil producers themselves, outside of the Bradford, Pa., field, flooding has been regarded with almost universal disfavor because of their many unfortunate experiences.

Unlike the other methods for increasing recovery, a flood passing through the sand leaves the oil not brought to the surface practically irrecoverable. After any one of the other methods has been used the sand can still be flooded or any other process can be employed which may be discovered in the future, but flooding marks the end of the field, and it is not likely that it will ever be practicable to pump out the water or to employ other methods. For this reason flooding

^a Carll, J. F., The geology of the oil regions of Warren, Venango, Clarion, and Butler Counties: Second Geol. Survey of Pennsylvania, vol. 3, 1880, pp. 256-289.

^b Huntley, L. G., Possible causes of the decline of oil wells and suggested methods of prolonging yield: Tech. Paper 51, 1913, pp. 9-21.

^c Johnson, R. H., and Huntley, L. G., Principles of oil and gas production, John Wiley & Sons, New York, 1916, pp. 141-144, 158-161.

should not be employed until it has been demonstrated that it will recover as much oil as other methods and as much as can reasonably be hoped for from future discoveries.

The chief exception to the generally unfavorable opinion of flooding held by the producers is in the Bradford, Pa., field, where a majority of the oil men have arrived at a more favorable opinion, so far as local conditions are concerned. Because the Bradford field is almost the only place where flooding is carried on systematically, most of the discussion on the increasing of oil recovery by displacement with water is devoted to results with flooding in this field. Natural conditions seem to be exceptionally favorable at Bradford for the use of flooding and even the most enthusiastic local advocates believe there are few other fields where flooding would be even partly successful, and that what has been accomplished at Bradford can seldom be hoped for elsewhere. The exceptional opportunities in this field for studying the effects of flooding make the experiences and opinions of the Bradford operators well worth recording.

THEORY AND PRINCIPLES OF FLOODING.

Flooding is based on the theory that to remove the oil retained in the oil-bearing formation by capillarity, adhesion, and frictional resistance after the exhaustion of the gas, something must be introduced to displace the oil and refill the spaces it had occupied. Water is introduced into the field to displace the oil from the pores in the oil-bearing formation, concentrate it ahead of the flood of water, and force it into pumping wells through which it is brought to the surface.

Huntley^a gives the following summary of the principles of flooding, to which the writer has made some additions, in brackets:

The main factors affecting the flooding of an oil-bearing formation may be summarized as follows (adapted from Carrl):^b

(a) Time of flooding—whether early in the process of operations, while yet a large percentage of oil and gas remains unexhausted, or at a later period after the supply has suffered from long-continued depletion.

(b) Composition and thickness of the formation [whether loose or consolidated], whether regular and homogeneous throughout or composed of fine sand interbedded with irregular layers of gravel, in places lying near the top and in places near the bottom.

(c) Position of the pool—whether flat, as on a structural terrace, upon a monoclinical slope, upon the crest of an anticline, or at the bottom of a syncline [and what the angle of dip is].

(d) Shape [and size] of the area being flooded.

(e) Position [and number] of the point[s] at which water is admitted in reference to the situation of surrounding wells still pumping oil.

^a Huntley, L. G., Possible causes of the decline of oil wells and suggested methods of prolonging yield: Tech. Paper 51, Bureau of Mines, 1913, p. 20.

^b Carrl, J. F., The geology of the oil regions of Warren, Venango, Clarion, and Butler Counties: Second Geol. Survey of Pennsylvania, vol. 3, 1880, p. 265.

(f) Height of the column of water obtaining admittance.

(g) Duration of the water supply. It will readily be seen that a temporary flooding in comparatively fresh territory, as from the drilling of new wells without casing and from the overhauling of old ones having the seed bag attached to the tubing in the primitive way, must necessarily be a different affair from a flooding caused by a permanent deluge through unplugged and abandoned wells in nearly exhausted territory.

(h) [Character of the oil and of the water].

These factors are considered in detail in Huntley's paper and some valuable facts are given. The same subject is also considered briefly in Technical Paper 130.* Some phases of the subject have also been treated in previous paragraphs of this report.

Until the oil-bearing formations have been partly exhausted, little water can enter and extensive flooding is seldom possible. It can not be held that the water entering the sand displaces an equal amount of oil, that is, barrel for barrel, for part of the water occupies pores from which the oil has long since been removed, nor does the water force out and displace all the oil remaining in the pores.

The water entering the productive formation may be the water generally found in the same formation at lower levels which rises into the productive parts upon the escape of the gas and part of the oil that previously had held the water in place, or it may enter from other strata and even from the surface through defective wells. It may be in comparatively small quantities, which can be produced simultaneously with the oil; or it may enter the sand in such large volumes that either the wells can not be pumped at all or not profitably. The water may enter for only a short period or indefinitely. Most oil wells produce some water, and in the eastern and middle western fields often a relatively large part of the fluid produced during the later life of the well consists of salt water. In the eastern and the Mid-Continent fields, where the oil is light and of paraffin base, small quantities of salt water are generally considered more beneficial than injurious, as the producers believe it flushes the oil from the sand and lessens the deposition of paraffin that would clog the pores and obstruct the passage of the oil. In California, however, the experienced producers regard even small quantities of salt water as detrimental.

HOW A FLOOD SPREADS THROUGH AN OIL-BEARING FORMATION.

If the oil sand were level and the conditions were uniform in all parts, the water entering from one well would spread in an ever-widening circle whose area would increase as the square of the radius. If in the first year the water reached 100 feet from the

* McMurray, W. F., and Lewis, J. O., Underground wastes in oil and gas fields and methods of prevention: Tech. Paper 130, Bureau of Mines, 1916, pp. 5-9.

well, in the next year, assuming the same quantity to enter the sand, the water would travel but 41.4 feet farther; in the third year 31.8 feet farther; and each succeeding year the rate of movement would become less and less. But because of a number of factors always or ordinarily present the actual decrease in rate is much greater. Among these factors are the increased resistance with the distance penetrated and the quantity of oil accumulated ahead of the water, a tendency for the pores of the sand to become clogged with silt and waxes and for the flooding well to become choked with material caved from the walls of the hole and a probable diminution of the water supply. The result is ordinarily a marked slowing up of the spread of a flood from year to year, unless new sources of water are added. It has been noted many times in the Bradford field that the water may penetrate 200 or 300 feet from a well the first year; but after several years the movement is apt to be not more than 30 to 60 feet yearly, and when a distance greater than 500 or 600 feet has been reached the movement becomes exceedingly slow and almost ceases. But if the water enters the sand, not from one center but from a row of wells, or is encroaching from the lower levels of the oil sand, the advance of the flood does not decrease so rapidly from year to year.

A modification of these conditions might be found in a new field. At first, before much oil had been pumped from the sands and while the gas pressure remained high, the water could not enter nor move rapidly, but with the removal of oil and the reduction of gas pressure, the flood could move faster.

As the oil sand is never level nor uniform in all parts, the water does not move equally in all directions nor at a uniform rate through all parts of the sand, and the greater the divergence from these ideal conditions the more irregular in shape will be the area affected. Huntley^a has described the movements of a water flood as follows:

When water is admitted in large quantities it tends to flow out in various directions, the greatest flow following the line of least resistance. Owing to the differences in the resistance offered by sands of differing porosities and to varying amounts of gas [or oil] in the rock, this movement of the water and oil in regions of low monoclinal dip—say, 15 to 20 feet to the mile—will extend up the dip as well as down. The movement will be particularly strong in the direction of very porous lenses and toward pumping wells, regardless of the effect of gravitation, the suction created by the pumping wells being sufficient to overcome the relatively slight tendency of the fluid to flow downward. This effect sometimes causes wells situated above the point of flooding to be affected ahead of the water wave and abandoned before those down the dip are affected. As an additional result, the water wave, aided by irregularities in the structure and shape of the pool, will sometimes surround bodies of oil that were originally

^a Huntley, L. G., Possible causes of the decline of oil wells, and suggested methods of prolonging yield: Tech. Paper 51, Bureau of Mines, 1913, pp. 18-19.

a part of the pool. Two or three such isolated pools are mentioned by Carll as having been discovered on the outskirts of the Pithole oil pool after the central part had been flooded.

Again, lenticular pebble beds or lenses of unusually porous sand may form pockets in the upper part of an oil sand and may catch quantities of oil, which are retained as the main body of oil advances ahead of the water wave. These pockets furnish the oil in many wells that are entirely surrounded by flooded territory yet continue to produce a little oil along with large quantities of water.

How great an effect the porosity and size of the sand grains and other irregularities in the contents, character, and texture of an oil sand have upon the relative resistance may be gained from the figures quoted from Slichter (see p. 18) and from the experiences gained in forcing air through oil sands in the Smith-Dunn process.

Not only will the line of least resistance be down the dip and toward the pumping wells through the most coarse and porous parts of the oil sand, but will be through the parts containing the least oil. A part that formerly has contained only gas, provided the texture is not too tight, will afford less resistance than a part where much oil remains.

These differing conditions in the oil sands that affect resistance are at times more important than a considerable slope in the formation, as is shown by a case reported from the Coalinga field, California, by M. J. Kirwan, State deputy petroleum and gas supervisor.^a In spite of a dip of 27 feet to the hundred (over 1,500 feet to the mile) the water traveled faster along the level and up the slope of the formations. The same case also shows the irregular movements of water spreading through the sand from one well.

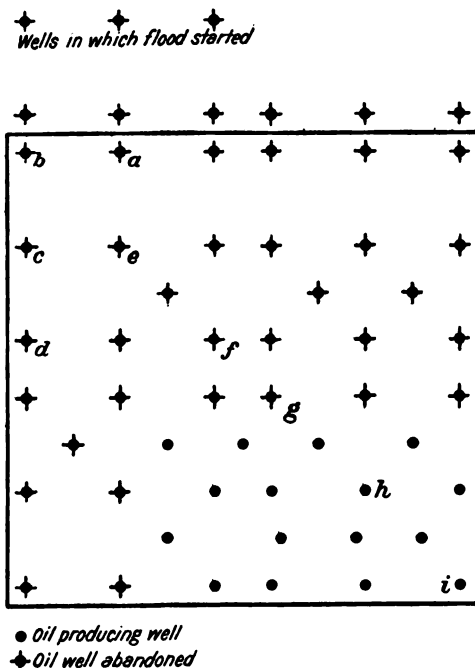
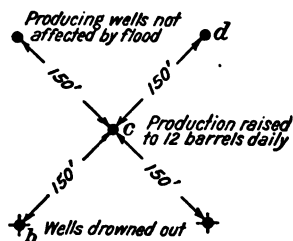


FIGURE 26.—Diagram showing movements of water on oil property in the Kane field near Bradford, Pa.

^a First Annual Report of the State Oil and Gas Supervisor of California for the Fiscal Year 1915-16, Bull. 73, pp. 110-115.

The irregular movement of a "water drive" is also illustrated in figure 26, the information being supplied by one of the largest and most responsible operators of Bradford, Pa. The flood took place on a property in the Kane field near Bradford, Pa., production being



◆ *a. Flood started in these wells* ◆

FIGURE 27.—Sketch of a group of wells in the Bradford, Pa., field, showing how short a distance wells are affected ahead of a water drive.

obtained from the Kane sand which underlies the Bradford sand by 265 feet. The flood started at several well locations from the property and advanced gradually, affecting wells *a* and *b* first, the water coming in and drowning out the wells almost simultaneously with the increase in production, so that little benefit was obtained. Wells *e* and *c* were affected next, well *c* being drowned out quickly, while well *e* produced a large quantity of flood oil and was not abandoned until long after other wells near by had been drowned out. Wells *d*, *f*, *h*, and *i* were affected progressively, wells *d* and *f* having been drowned out, while wells *h* and *i* were still producing, but the water passed entirely around well

g, affecting all the other wells near by, although well *g* was not affected until recently, when it began to make much water and a little more oil than formerly. At the time this was written, of the 48 wells on the property 16 were still producing.

As the water will travel most quickly through the lines of least resistance it will advance through one layer in the sand and drown

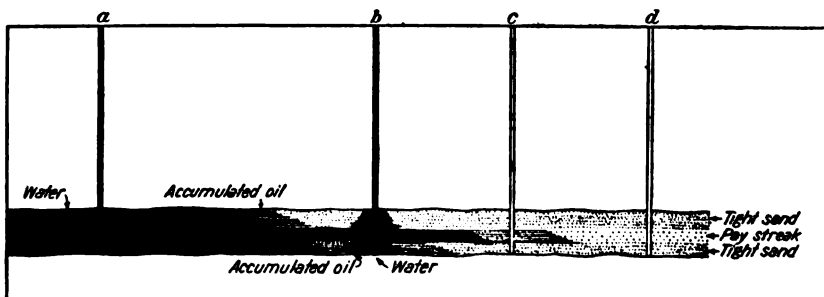


FIGURE 28.—Section through wells *a*, *b*, *c*, and *d* in figure 27, showing probable conditions in the oil sand being flooded.

out the wells before they can be benefited from the oil that has accumulated in the less porous parts of the sand which will always lag behind. This principle is illustrated in figure 28, which is the probable explanation of the actual conditions shown in figure 27. It also

explains the conflicting reports of conditions in wells drilled into flooded areas in the Bradford field, where some operators report that the sand was found waterlogged from top to bottom, as in well *a*, figure 28, whereas others found that only a minor part of the sand contained water, the rest of the sand showing oil, as between wells *b* and *c*, figure 28. Evidently the water, when it enters the oil sand, does not stratify with the oil making a level surface between the two fluids, for then there could be no such condition as is shown in figure 27 and as has been reported in other instances, where of three wells drilled within 150 feet of each other in a thick sand lying practically level, one is flooded out, one is producing flood oil, and the third is not affected. Either the water advances in a wall, the front of the flood being nearly perpendicular, or, as is most likely, it travels fastest through a comparatively thin layer in the sand in the manner illustrated.

In view of the many variable factors influencing the movement of the water, it is not surprising that the rates at which the water travels and the area affected by one well vary widely in the different oil fields of this country. It must not be inferred that the slow movements of water shown by experience in the Bradford field are usual, for they are evidently unusually slow and restricted even for the eastern fields. In contrast the water has been known to travel through the sands in California fields distances in days that it would take years to advance in the Bradford field, and one well has been known to seriously injure large areas.

An instance of water movements through oil sands under conditions different from those in the Bradford field is reported by F. B. Tough, of the Bureau of Mines. In a part of the gusher district in the Midway field of California, where the wells are 3,000 to 3,500 feet deep, the oil of a specific gravity of 27° B., and the sand fairly fine grained, the pumping of one well that was badly troubled by water would decrease the proportion of water in another well situated farther down on the dip and 400 feet distant from 70 per cent to 2 per cent and raise the oil production from 60 barrels to 130 barrels daily within 36 hours. If pumping were stopped in the first well, the water would flow through the sand and cut off the production in the second well in 36 to 48 hours.

Similar cases have been reported elsewhere in California fields, the general experience being that water travels quickly, irregularly, and in large volumes through the oil sands. From the Coalinga field, Kirwan^a reports an instance where the edge water encroached upon the extraction of the oil and relief of gas pressure higher up the dip in the oil sand, about 800 feet in 6 years. But in the case

^a Op. cit., p. 83.

previously cited where flooding was caused by a defective well, another well about 1,000 feet distant was affected within 5 months.*

RELATION OF GEOLOGIC STRUCTURE TO FLOODING.

Where the dip is low its effects on the movement of water are likely to be less than that of other factors, as at Bradford, but where steep it may be the controlling factor and cause practically all the water entering the oil-bearing formation to flow in one direction. In such a case there will be a tendency for the water to follow channels, and there is not likely to be much increase of oil production in wells affected by the flood unless the water is introduced at the lower edges of the field so that it must rise up the dip. Theo-

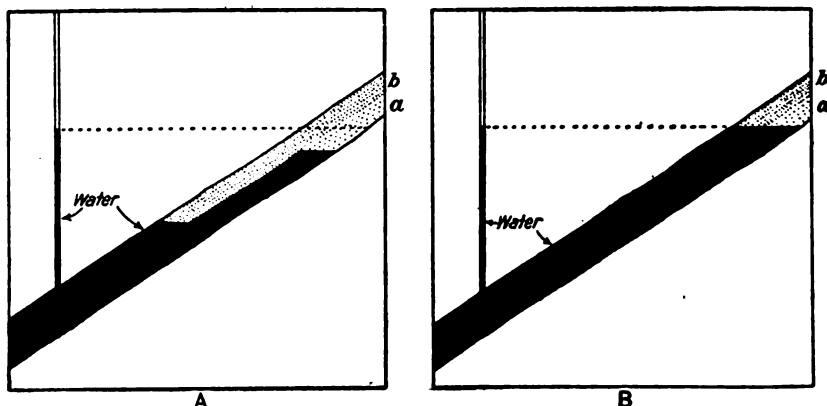


FIGURE 29.—Diagram illustrating the theory of flooding up the dip. Water is let into the well and rises up the dip, progressing faster and reaching equilibrium first in the layer of least resistance, *a*, as shown in A. If the water column in the well is not increased, the water will also rise in the tight part of the sand, *b*, and reach equilibrium, as shown in B. By carefully restricting the quantity of water entering the well and the height of the water column, it is sought to make the water rise equally in all parts of the sand.

retically the water should always be introduced in this way, because it is heavier than the oil, thus forcing the latter toward the higher parts of the oil-bearing formation, but the movements are at times so slow and so little controlled by the dip that sometimes it would be impractical to flood a large field in this way, as in the case of the Bradford field.

It has been suggested that the troubles arising from the varying rates of movement of the water through the different parts of the sand caused by the diverse conditions might be overcome by letting the water rise up the dip. This principle is illustrated in figure 29, which represents the simplest conditions. If the water column in the well were maintained at the same height, the water would rise through the sand up the dip till it stood at the same level, but would

* Op. cit., pp. 110-115.

reach this level first in layer *a*, which offers less resistance than *b*, as shown in A. By introducing the water no faster than it would advance through *b*, the water should advance on a level through the sand as shown in B, so that the trapping of the oil in the tighter parts of the sand would be lessened.

In the practical application of this principle, the trapping of oil would be difficult to avoid even where flooding was carried on with complete cooperation among the producers of the field, and after the most painstaking investigations of the underground conditions had been made. The first problem that suggests itself is how to determine how fast the water is moving through the different parts of the sand, and the rate at which the water should be fed into the sand at each well to avoid the faster progress of the flood through some parts than through others. If the sand were level this irregular advance could not be prevented no matter how slowly the water were let in, for the principle is based upon keeping an approximate balance of pressure between the water that has risen in the sand and that standing in the well (see fig. 29). If the sand had a low dip, say 20 feet to the mile, and was 40 feet thick, the water would have to advance 2 miles along the bottom of the sand before it would strike a level through the sand and reach equilibrium in all parts. To prevent irregular advance of the water and trapping of oil under such conditions of relative dip and thickness of sand, which approximate the conditions in most fields east of the Rocky Mountains, only a very low column of water could be held in the well and consequently the advance of the water in a field like the Bradford, where the advance is slow under water pressures of 1,000 feet or more, would make flooding on this principle impracticable. Where the dips are relatively steep it would still be necessary to use very low pressures. It must be remembered that along a line at right angles to the dip, the bed lies flat and that the water entering from a well if it can not go down the slope, will move laterally rather than up the dip, and in these directions the conditions outlined above prevail even where the dip is steep. For this reason the flooding would have to be started along a row of wells and there would be difficulty in regulating the advance from each well because of the varying resistance and dip of the sand from place to place.

The rise of the water being from the bottom of the sand upward, it would be necessary to plug the bottom part when the water reached the well; otherwise it would rise into the well and increase producing costs, or drive the oil back into the sand. The bottom plugging of the hole would have to be done periodically with the rise of the water.

For these reasons the writer believes that attempts to avoid the trapping of oil by flooding up the dip can seldom be successful in practical operations.

EFFECT OF HYDROSTATIC PRESSURE ON FLOODING.

If the water is under high hydrostatic pressure more water will enter the sand and it will move faster than if the hydrostatic head is low, but there has been some confusion in regard to the pressures actually exerted by the water upon the oil, and the effects that pressure has in displacing the oil from the sand. At the bottom of the well where the water enters the sand the full hydrostatic pressure of the column of water standing in the hole is exerted, but in the oil-bearing formation the actual pressure exerted becomes less and less away from the hole in accordance with well-known laws governing the loss of head or pressure of a fluid flowing through pipes or sand in which there is frictional resistance. At the edge of the flooded area, where the oil is being displaced and driven ahead of the water, the actual hydrostatic pressure exerted may not be large, neither is the hydraulic force of the moving water much, for after the flood has extended for a distance of several hundred feet from its center the advance often becomes very slow. For example, at a rate of 100 feet yearly, which is more rapid than the average in the Bradford field, the advance is less than $3\frac{1}{2}$ inches daily, which is about one-third the rapidity of the movement of the hour hand on the ordinary-sized watch. At such a slow rate the water passes through the sand quietly, and is not turbulent nor accompanied by agitation. In fields where the water travels most rapidly, as in California, production is not often increased by flooding.

TRAPPING OF OIL BY WATER.

How oil may be trapped by water has been brought out in former paragraphs. It may be caught by irregularities along the top of the oil sand, or by barriers in the oil-bearing formation. (See fig. 2, p. 15.) Because of the diverse conditions, the water advances more rapidly through some parts of the oil-bearing formation, surrounding or making unavailable the oil in the other parts. (See fig. 28.) The layers in the oil sand are seldom uniform for long distances along the bedding, as assumed in figure 28, but are variable even in the most uniformly bedded sands so that one layer may be porous in one place and tight in another, or the partings present in one place may be absent in another; consequently the water will now and then cross from one layer into another ahead of the oil and trap it, or the oil may be driven into pockets and held there. In addition, the converging of floods starting from many centers and the tendency for the water to advance to and drown out producing wells ahead of the general front of the flooded area greatly increases the quantity of trapped oil. The more irregular the conditions in the

oil-bearing formation, and the more numerous the centers of flooding, the less complete will be the recovery of oil. Once the water reaches a well, production seldom can be continued because usually the water is in quantities too large to permit profitable operation, and the oil remaining in the sand becomes practically irrecoverable.

INCOMPLETE DISPLACEMENT OF OIL BY WATER.

It has been shown how bodies of oil may be trapped in the oil-bearing formation because of the irregular structure. Next may be considered how completely the oil is displaced from the pores where conditions are fairly uniform in the formation. The principal conditions in a sand being flooded are: The water moves slowly, without agitation; the pressure may be high at the place where the water enters, but is likely to be low at the front of the flooded area, where displacement of oil is taking place; ordinarily temperatures will be somewhat higher than the average surface temperatures; the water may be fresh or salt; the oil may range from the lightest paraffin oils to the heaviest asphaltic tars; the oil-bearing formation may be fine tight sand, loose gravel, or vesicular dolomitic limestone.

A few elementary experiments conducted under conditions far more favorable than could be hoped for in oil sands underground, indicate that much of the oil may not be removed by passing water through a sand. In the experiments described on page 23, fresh water at 70° F. was passed through tubes of well-drained sand containing 15 to 53 per cent of the original volume of oil with which it was saturated, yet in only one experiment was there even a color of oil on the water after it had passed through. Likewise no oil was removed from sand from which the oil had been expelled by compressed air or gas, though the water was under 50 pounds pressure. This series of experiments covered a range of conditions from light crude oil from Bradford, Pa., having a gravity of 41° B., to heavy California crude oil with a gravity of 14° B., and two uncemented sands, one medium grained and the other fairly coarse. When water was allowed to rise through sand fully saturated with oil, a slightly larger percentage of oil was retained, but much of the oil displaced was accompanied by a larger proportion of water that would have made production unprofitable in the field. When the sand was partly drained of oil before water was passed through, a much larger proportion of oil was left in the sand, the water showing a marked tendency even in the upright tubes of uniformly packed sand for sidetracking and surrounding bodies of oil. For example, a tube full of the same coarse sand, which would retain a minimum of 15 per cent of the Bradford oil after long draining, was saturated with the oil, 22 per cent was drained out, and

water was then allowed to rise slowly through the bottom. Thirty-seven per cent more oil was displaced before water showed at the top, and then an additional 6 per cent with almost ten times as much water as oil. At this point the ratio of water to oil in the mixture increased to 20 times as much water and quickly to 100 times as much water as oil. A volume of oil representing 35 per cent of the capacity of the sand and 45 per cent of the original quantity of oil remained in the sand when the water had reached a proportion that would make production unprofitable in a well.

These experiments show that the water enters the drained pores first, trapping a large proportion of the oil in the undrained pores. In a bed of oil sand partly drained and lying at a low dip, it can reasonably be expected that only a small proportion of the oil will be displaced, even where the conditions are most favorable. From this it can be understood how even at Bradford the recovery by flooding is still but a small fraction of the apparent content of the sand. The recurrent floods, reported by Huntley as taking place periodically at Oil Springs, Canada (see p. 106), yield more oil on each advance and recession of the water, showing that not all the oil is driven into the wells at one passage of the water through the formation.

Johnson has suggested the use of compressed air in conjunction with water in flooding. Johnson^a says, "Theoretically, it would seem wise to keep the wells farther down the dip open, so that compressed air could be forced in. This air, bubbling through the water-filled sand, ought to disengage some oil that the moving water alone could not dislodge. The accumulation of the air in little domes and pockets in the top of the sand would dislodge oil that had been retained there, so that it would move on up the dip to the pumping wells. Whether this compressed air system will warrant the expense, only actual trial can prove; but judging from the outcome of laboratory experiments, the prospect is promising."

In the Smith-Dunn process the air increased the yield of water quicker than the production of oil, and hence if the air were introduced in large volumes it may be expected to be more detrimental. The recurrent floods, reported by Huntley as taking place periodically might aid in displacing the oil from the sand without this harmful effect; but it can hardly be expected to overcome fully the chief practical difficulty in flooding which is caused by irregularities in the sand that influence the movements of the air as much as those of the water.

HOW OIL MAY PASS BETWEEN THE WELLS.

When an oil sand is first opened up the pressure is fairly uniform throughout the oil-bearing formation, and a well drilled into it

^a Bacon, R. F., and Hamor, W. A., *The American Petroleum Industry*, vol. 1, 1916, pp. 430-431.

becomes the center of converging movements of the oil from all parts of the surrounding area; but when the oil-bearing formation is being flooded by water let into one well, the motive force spreads out from the center, the oil accumulating ahead of the water and around the edge of the flooded area. As the flood advances the oil directly in the path of the water is forced into producing wells, but there is little force acting to bring the oil into the well from either side along the front of the flood. This condition differs essentially from the original one, for there is now no force to bring the oil in from all directions toward the pumping well, the force being applied practically in only one direction, so far as each producing well is concerned, so it is very likely that a producing well gets the oil from only a small segment along the front of the flooded area, the rest of the oil passing by when the well is drowned. The quantity of oil obtained from a well during the approach of the flood may be larger if it is an old well, because the sand has been more completely drained around the well and oil is being constantly removed, so that the oil tends to move toward this point of low resistance. However, this also creates a tendency for the water to be drawn toward the well, and probably the water reaches and drowns producing wells in advance of the general progress of the flood. In the Coalinga field, California, a tendency has been noted for the approaching water to send out finger-like projections toward the oldest or largest producing wells or where the sand has been most completely drained. Because of this tendency for oil to pass by the wells it is desirable to drill the wells close together and place the wells of each succeeding row in advance of the flood intermediate between the wells in the row ahead to prevent some of the oil from being trapped between wells. This is one of the reasons why wells in advance of the flood are drilled close together in the Bradford field.

FLOODING IN THE APPALACHIAN FIELDS.

A detailed description of the Bradford field and the results obtained by flooding in that field are given in pages 108 to 117, it being considered that Bradford presents the most favorable conditions for flooding and the best experience in conducting a flood. A few instances of flooding in other fields where the yield has been affected are briefly described in the following:

The most notable of the floods which occurred in the early fields was at Pithole, Pa., and has been described by Carll.^a The flood was caused by lack of effective ways of excluding water and through lack of knowledge of the effects of large quantities of water entering

^a Carll, J. F., The geology of the oil regions of Warren, Venango, Clarion, and Butler Counties: Second Geol. Survey of Pennsylvania, vol. 3, 1880, pp. 268-269.

the oil-bearing formations. The flood advanced rapidly and irregularly, and within a period of a few years almost the whole field was drowned out. Some of the wells in the path of the water showed remarkable increases in yield before being drowned, but attempts by operators to foretell or to control the movements of the water were usually unsuccessful. Carll mentions the discovery, after the central part of the field had been flooded out, of several isolated pools of oil trapped on the outskirts.

Carll also describes several other isolated pools of trapped oil in the Oil Creek field, Pa. Floods in other Appalachian fields have usually resulted similarly in uncertain movement of the water, temporary benefits, and trapping of oil. Most often flooding has not paid, though occasionally a few properties have been considerably benefited, and it may have been the cause of some unusual yields.

FLOODING AT OIL SPRINGS, CANADA.

Huntley^a gives the following description of a flood taking place in the Oil Springs pool, in Lambton County, Ontario:

The entering water may shift the whole body of oil from its original position, the extent of such shifting depending on the dip and shape of the pool and its underground structure. The Oil Springs pool in Lambton County, Ontario, is an example. When the pool was first developed it produced from a shallow "pay," an open vesicular stratum in the Corniferous limestone. The wells were all dug and were cased with Scotch casing of large diameter. At the time of the Fenian raid the field was temporarily abandoned. When operations were later resumed it was found that the lower part of the casing in a great number of the wells had been corroded away, the wells had caved, and great quantities of fresh water from swamps on the surface had flooded the oil-bearing formation. Deeper drilling developed the present "pay" stratum at a lower depth, and the old wells were abandoned, as they could not, of course, be plugged.

In recent years wells drilled through this shallow stratum showed that the water had decreased, and one well struck oil. Other wells were drilled and an attempt was again made to pump off the water.

These operations developed the fact that after the spring rains or any large freshet quantities of fresh water seeping into this porous formation caused the water level to advance up the sides of the anticline upon which the pool is situated, carrying before it a considerable body of oil. By pumping certain wells located at strategic points in progressive rotation, as the water and oil advanced or receded, considerable oil was recovered.

It was noticed that more oil was recovered upon the recession of the water than upon its advance. As the water advanced, a part of the oil was probably caught and retained in the porous irregularities on the roof of the stratum. As the water receded these were again taken up by the main body of oil, increasing its quantity. This supposition is supported by the fact that a few wells would continue to produce a little oil with the water after the surrounding wells had all been flooded by the advancing water. This theory is illustrated in figure 30; 1 and 2 represent wells through which flooding takes place, whereas

^a Huntley, L. G., Possible causes of the decline of oil wells and methods of prolonging yield: Tech. Paper 51, Bureau of Mines, 1918, p. 19.

A, A', B, and C represent wells pumped successively for oil as the water changes the relative position of the oil body.

One well is reported to have yielded 1,300 barrels of oil in three days before failing. As these shallow wells must be worked at great speed to effect a maximum recovery before being again flooded, pumps of large diameter and quick stroke are used.

The reader should note that one advance or recession of the flood removed only a part of the recoverable oil, yet ordinarily the operator must be content with what is obtained during a single passage of the water through the oil sand.

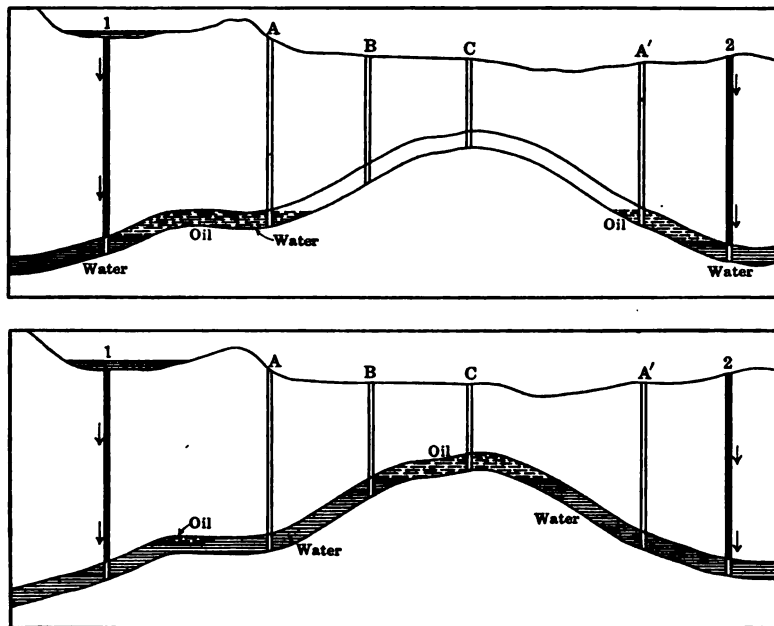


FIGURE 30.—Effects of flood water and arrangement of wells drilled to utilize flood-water pressure.

FLOODING IN THE KERN RIVER FIELD, CALIFORNIA.

The Kern River field in California provides another instance of the effect of flooding where the natural conditions differ considerably from those of the other fields described. Wells in this field are 600 to 1,200 feet deep, the oil is very heavy and viscous and comes from a zone of unconsolidated sands several hundred feet thick, made up of sand lenses interbedded with layers of clay irregular in thickness and extent. Large quantities of water entered the oil sands, some of it coming from strata above and some from strata underlying the oil sands. So much water accumulated in parts of the field that many wells were abandoned and it became necessary to employ special means to rid the field of water in order to continue production. Air

lifts were installed by which large quantities of water could be brought to the surface, and by pumping certain wells, called key wells, the water level was lowered in the adjacent parts of the field. The invasion of the water into the sand and its later removal had noteworthy effects upon the productiveness of some parts of the field. Near the center of invaded areas where the wells were most affected by water the productions were considerably decreased, whereas the productions of wells farther away were appreciably benefited. After the air lifts had lowered the water level, those wells which had been benefited decreased in production, and in one part of the field, when the use of air lifts was discontinued for a period and the water reaccumulated, production increased once more in the outlying wells.

FLOODING IN THE BRADFORD FIELD.

HISTORY AND DESCRIPTION OF THE FIELD.

The Bradford field is situated in the northern part of Pennsylvania, a part of it extending over the line into the State of New York. It is one of the largest fields ever developed in the United States, both in area and production. Development started in 1869 and to date (1915) about 230,000,000 barrels of oil, nearly one-third of the total combined productions of Pennsylvania and New York, have been produced from about 85,000 acres, with an average yield of about 2,700 barrels per acre. The wells completed early in the life of the field came in with flows ranging up to several hundred barrels daily, but now the initial yields of new wells average about three barrels daily, whereas the yields of older wells not affected by flooding are only one-tenth to one-half barrel daily.

The Bradford sand is the third in the local series, the first and second sands being practically nonproductive. Ashburner* says—

The Bradford oil sand is the most important economic stratum in the northern tier of counties. It consists of gray and white sand of about the same coarseness as the ordinary beach sand of the Jersey coast; compact, yet loosely cemented. The average thickness of the sand is about 45 feet, and from top to bottom the sandy strata change but little in their general character. It is only when specimens from successive layers are placed side by side and closely examined that any difference in structure can be noticed. The grains of sand are angular, vary but slightly in size, color, and quantity of cementing material, which holds them together in their rock bed.

The same homogeneousness which characterizes the vertical section is found to exist over a considerable horizontal area. In fact, but little change is found to exist in the sand obtained from wells 15 miles apart, or in the sand from intermediate wells.

Operators in the field report that the sand near the top is apt to be hard and practically nonproductive. Most of the sand shows

* Ashburner, C. A., Report R: 2d Geological Survey of Pennsylvania on McKean Co. 1880, p. 75.

oil, but the large productions obtained during the early lives of the wells came mostly from "pay streaks," which were strata in the oil sand that were no coarser but were less consolidated than the rest of the sand. These "pays" are usually 5 to 10 feet thick and may be in any part of the oil sand, but are usually in the middle part, and there may be two or three "pays" in the same well separated by tighter parts of the sand or by shale breaks. Frequently, in shooting the old wells, the former "pays" do not respond as well as the tighter parts of the sand. Other writers besides Ashburner state that conditions are remarkably uniform throughout the field and that within the productive area not 3 per cent of dry holes have been drilled, for although the individual "pays" may not extend over the whole field, there is usually some pay sand in every well. The strata lie almost horizontal, the average dips being 10 feet per mile, according to Ashburner. On only one flank is the field outlain by salt water, the sand being either barren or containing only gas on the other edges of the field.

In depth the wells range from 1,200 to more than 2,000 feet, depending largely on the topography. Usually the only casing used is to exclude fresh water, which is found within 300 to 400 feet of the surface in the valleys, and, as drilling conditions are very satisfactory, the wells are, relative to their depth, inexpensive even for the Appalachian field. Pumping costs are low because it is seldom necessary to pull the casing, pumping trouble being infrequent, but on account of the small productions the margins of profit do not permit the producer to make extensive repairs and replacements except during periods of high prices, and usually a well is abandoned if anything goes wrong. Attempts to increase production by gas or vacuum pumping at low pressures as in other fields have been generally unsuccessful and gas pumping is employed only to relieve the wells of back pressure in order to increase the gas supply for fuel and for making gasoline by compression. The wells are not usually pumped by "powers and jacks," but most frequently are pumped "on the beam" (see Pl. IV, *A*) or by air or steam heads (see Pl. III, *B*). Air compressed in compressors driven by gas engines is the most common source of pumping power.

OPINIONS OF THE PRODUCERS ON FLOODING.

Practically the only place where flooding has been even comparatively successful is in the Bradford field, where conditions are exceptionally favorable. Flooding has been going on in this field for over 20 years, although it is only within recent years that it has received favor and attention. The flooding started accidentally from old abandoned wells which had been improperly plugged or not

plugged at all. Through these old wells fresh water from sands near the surface entered the oil sand and drove the oil to the pumping wells near-by. At first the flooding was looked upon as an unmixed evil, but when it was found that yields of oil wells were greatly increased and were maintained for periods of several years, and more profits were being derived than otherwise could have been obtained through an indefinite term of years by ordinary pumping, some of the operators concluded that flooding was beneficial and endeavored to make use of the principle to increase the production of their properties.

Though opinion among the operators in this field is by no means unanimous, the majority of the men working in the field appear to favor flooding openly, although most of the larger producing companies are opposed to it.

SOURCE OF THE WATER USED.

As stated previously, mostly fresh water derived from shallow sands is being used for flooding in the Bradford field, and, except for the salt water on one edge of the field, is the only supply in sufficient quantities and under sufficient pressures that is available. The downward migration of this fresh water has seriously affected the supply for domestic use in some parts of the field, and it is reported that springs and wells have gone dry in the vicinity of some properties where flooding is going on. Flooding on an extensive scale in this field as in others is largely dependent upon the available water supply. Doubtless in some fields and in some localities flooding, except on a relatively small scale, would be impracticable from lack of an adequate water supply under sufficient pressure, whereas in other fields or properties a depletion of the fresh-water supply would be seriously objectionable.

The flooding first originated in old abandoned wells as stated, but it has been claimed that some operators have allowed the water to enter wells by raising or splitting the casing or have conducted the water to the oil sand through pipe. Where no provision has been made to prevent the water standing against the walls of the hole, they cave and fill the hole, or mud is carried into the sand and clogs it. Also the water is likely to enter some of the sands above the Bradford sand and be wasted or pass through and drown out other wells in advance of the flood. A number of instances were reported by operators where wells were believed to be drowned out prematurely from this cause.

MOVEMENTS OF THE WATER.

As stated previously, the water moves more slowly every year that a flood continues. At Bradford the water may travel 200 or 300 feet

the first year, but in succeeding years the rate will be much less, and when the flood has reached a distance of 500 or 600 feet from the well in which it started, movement will practically cease, unless water is introduced through other wells nearer the front of the flood. Usually it is reported that the rate of progress is about 50 feet yearly. In what was probably the first flood in this field, started about 25 years ago, the water is reported not to have traveled more than 1,000 feet in any direction from the well from which the flood is supposed to have started, and within this area of about 70 acres 14 wells have been abandoned and 10 are still producing. Generally it requires several years, after flooding has started from a well in this field, before any of the surrounding wells are affected, and after the flood has passed the next well the rate of travel is likely to be 35 feet or less each year, so that it would take 10 or 20 years for the water to pass from one well to the next, as usually spaced. Because of this extremely slow movement of the water, it has been the practice to drill new wells close in advance of the flood rather than wait years for the next old well to be affected.

Because of the restricted area which one well will flood and the very slow movement of the water through the oil sand, it would be impracticable to flood the whole of the Bradford field except from many centers. Theoretically, it would be desirable to start at the edges, especially from the lowest levels, and to let the water advance up the dips, driving the oil ahead of it, toward the highest level, but in a large field like the Bradford where the advance is so slow, the properties in the interior of the field would be affected only after an impractical length of time, for at the average rates it would take the water 50 to 100 years to travel 1 mile, whereas the field is about 18 miles long by 12 miles wide. Consequently, if it were desired to flood the whole field, it would be necessary to let the water into the sand at many points. The starting of the many flood centers, even with carefully prearranged plans, would undoubtedly accentuate the losses from trapped oil and would lead to inequitable distribution of benefits.

The movements of the water in the oil sand at Bradford are not as irregular as in most fields where flooding has taken place, yet the water does not spread symmetrically from the center of a flood and its movements can not be predicted. No attempt was made by the writer to determine the effect of the dip of the oil sand in detail upon the movement of the water, but evidently this factor is not as important as other factors, such as the texture of the sand. As has been shown in figure 28, the water does not seek a level and stratify with the oil through the whole thickness of the sand, but advances most rapidly through a comparatively thin part of the sand which offers the least resistance.

PREPARING WELLS FOR "FLOOD OIL."

When an operator becomes aware of an approaching flood he puts the wells that he expects will be affected first into good condition for producing the larger quantities of fluid which must be handled. Usually the wells are shot and thoroughly cleaned out, and the pumping equipment is put into good order. It is becoming the practice to drill pockets 100 to 150 feet below the oil sand, so that when the production increases it will not be necessary to pump the well or pull the casing more frequently than before. If the existing wells are not situated to take the best advantage of the flood, new wells are drilled. As a usual thing, as soon as one well begins to show water and indications that it may be soon drowned a new well is drilled a short distance ahead, sometimes within 100 feet. This close spacing of the wells is made because of the very slow movement of the water and because of the tendency of the oil to pass between the wells if far apart. Where the flood is moving toward a neighboring property, wells may be drilled along the line to prevent oil from being driven across.

EFFECTS OF FLOODING ON ADJACENT PROPERTIES.

One of the chief objections to flooding has been the injury to other properties near by, but advocates of flooding at Bradford maintain that such is not the case there, and that the neighboring properties are more benefited than harmed. They point to the fact that a flood starting on their own property drives the oil toward the neighboring property, which is bound to get some of the oil. In recognition of this tendency for the oil to be driven across the property line and to be lost to the owner of the flooded property, the operators at Bradford drill wells on the property line, it being maintained that practically all the oil from such a well is driven into it by the flood, and that the drain on the neighboring property is not appreciable.

On the other hand, the adjacent producers, although they may receive some oil in this way, are subjected to a flood over which they have no control, and which they are compelled to accept no matter what their beliefs or the local conditions on their own property, nor can they be assured that they will get profits as great as might be obtained by some other method, such as the Smith-Dunn process, the use of which will be made impossible by flooding.

INCREASE OF PRODUCTION BY FLOODING AT BRADFORD.

The effect on a producing well depends largely on its distance from the flood center, and it is commonly reported in the Bradford field that yields of the first wells affected are not increased so much nor does the increase last so long as in the next wells. The first wells

affected have sometimes been drowned within a few weeks or months, with little or no increase of production, whereas wells located farther away have produced "flood oil" for several years. It is commonly stated by both advocates and opponents of flooding that the average well has been increased from its former production of one-tenth to one-half barrel daily to one between two and five barrels, which ordinarily is maintained two or three years. Occasionally the yield per well is increased to 10 or 15 barrels daily. One well reported to have been producing only one-third of a barrel daily in 1898, just before being affected by flooding, was reported to be producing two barrels daily in 1916, after being affected 18 years. Some wells abandoned many years ago have been cleaned out and made

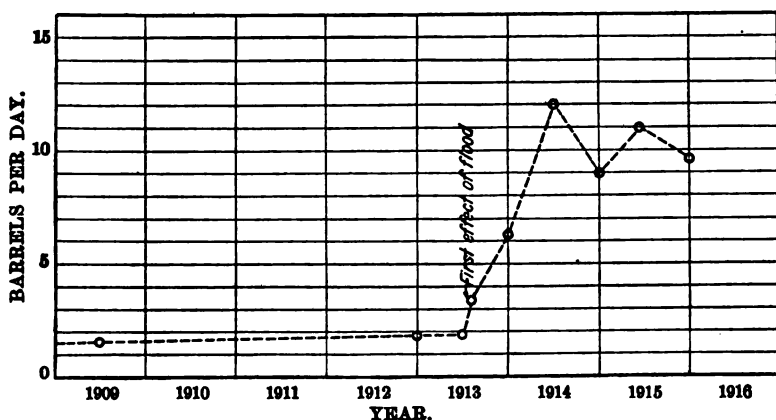


FIGURE 31.—Production curve of a property affected by flooding in the Bradford field. Previous to August, 1913, there were ten wells, later two new wells were drilled and an old well abandoned. Most of the oil comes from two wells, one 263 feet from the flood well. The property was first drilled in 1879 and is in the center of the field. An adjoining tract was too poor to produce, and recently three wells drilled were unprofitable. It has not been affected by the flood.

productive, and it is claimed that in a part of the field formerly always too lean to be profitable, the oil had been concentrated by a flood and production made profitable.

How the flood affected one property situated in the center of the field is shown in figure 31, the daily yields at intervals during the last 7 years being taken from the company records. Although only a small proportion of the wells were affected by flooding, the yield of the whole property has been increased by five or six times. Records of the same company showed that the average daily yield on nine scattered properties in the field was one-eighth barrel per well for 388 wells, whereas on four other scattered properties on which 18 wells out of 128 were producing "flood oil" the daily production averaged one-half barrel per well. Records of other companies showed increases for individual wells from the usual production of

less than one-half barrel to as much as 12 barrels daily. One of the most convincing facts showing the local opinion on flooding is that wells in line with floods sell at prices considerably above the average.

It is claimed by the advocates of flooding at Bradford that to date no property has been entirely flooded, and that not more than 2 or 3 per cent of the wells in the field have been drowned. Reports on wells drilled into a flooded area are conflicting. Some operators report the oil sand to be completely water-logged, whereas others report water only in part of the sand and state that sometimes the well can be pumped, but more frequently there is too much water to do so. An example of a well section through a partly water-logged part of the sand is 26 feet of hard sand showing oil, 10 feet of light brown sand showing much water, and 18 feet of hard sand showing oil. This corresponds to the condition shown between wells B and C in figure 28.

It is evident, from the facts cited, that flooding has greatly increased recovery, for at the low yields reached by the Bradford wells, and the natural decline of 5 to 10 per cent yearly, a well would have to be operated in the ordinary way for an almost indefinite period regardless of profits to obtain the yield obtained from the average well affected by flooding. Moreover, more wells are drilled to the same acreage than formerly. But compared with the capacity of the Bradford sand, the recovery is still low for, as shown previously, the capacity is at least ten times greater than the average recovery in the field to date, which has been about 2,700 barrels per acre. Present information does not permit a positive statement that the sand ever contained this much oil, but there are strong reasons for believing such was the fact, and that the total recovery even by flooding has been and will be only a part of the content of oil.

INCREASES OF PRODUCTION BY MARIETTA PROCESS AT BRADFORD.

Compressed air has been used, so far as known to the writer, on only two properties in the Bradford field to increase production and not extensively in either case. Good increases were obtained, and, considering the circumstances under which the process was used, the results are very encouraging for the use of compressed air or gas. In one instance gas under natural pressure was turned into the sand, but both the volume and the pressure were not sufficient to benefit production. It has been reported that on some properties gas from which the gasoline has been extracted by compressor plants has been returned to the oil sand, and that the dry gas was enriched again after passing through the sand, but it was not stated whether production was appreciably increased. In order to compare the effects

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of the Smith-Dunn process with flooding, the results on two properties are cited herewith:

Results of using compressed air on two properties in the Bradford field.

FIRST PROPERTY.

Well No.	Former daily yield per well, barrels.	Daily yield per well after applying compressed air, barrels.
1.....	1	4
2.....	1	5
3.....	1½ to 2	4½
4.....	1½	9
5.....	1½	5½
Total.....	5½ to 5½	28

Production was increased 5 times.

SECOND PROPERTY.

Well No.	Former daily yield per well, barrels.	Daily yield per well after applying compressed air, barrels.
1.....	1	4½
2.....	1	10
3.....	1	7½
4.....	1	5½
5.....	1	4
Total.....	3½	31½

Production was increased 9 times.

On the latter property air was forced into only one well, but benefited six producing wells near by. (See fig. 32.) From expe-

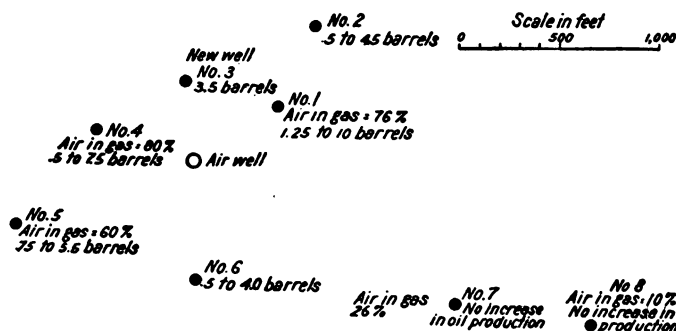


FIGURE 32.—Group of wells in the Bradford field, Pennsylvania, showing the effects of compressed air from one air well on oil and gas of surrounding wells.

rience with the process in other fields it is known that when air is forced into the sand from a number of wells over a large area the production is much benefited. Originally a pressure of 60 pounds was used, which was raised to 80 pounds, with a marked increase in yield of oil; then to 125 pounds, also with a marked increase in yields, but at this pressure the gas from wells near by, which was being supplied to a small town for domestic consumption, began to show more air than was thought desirable, and the use of air was discontinued and natural gas under natural pressure was used, but proved to be insufficient in quantity. Within three months the wells returned to their normal yields.

These figures indicate that probably yields may be increased in the Bradford field as much by compressed air as by flooding. From the

proportion of the oil in the sand may be recovered, for evidently the exhaustion of a well is caused more by the exhaustion of the natural expulsive forces than by the depletion of the supply of oil. If the natural gas associated with the oil is permitted to escape unrestricted and without performing the greatest amount of work possible, the producer is lessening the quantity of oil that may be obtained by natural means. Every foot of gas produced wastefully may be considered to represent a quantity of oil that should have been brought to the surface by using the gas effectively. It appears logical to gage the efficiency of production methods by the relative volumes of gas produced with the oil at the same well. If, for example, a change in method reduced the volume of gas produced with each barrel of oil from 2,000 to 1,000 cubic feet, much more oil could be recovered eventually, even though the actual daily production of oil were reduced a little temporarily.

Few have realized to what a degree recovery is dependent upon the efficiency in utilizing the natural gas found associated with the oil, nor that it is possible to regulate, at least partly, the conditions of expulsion. Little effort has even been made to follow out the principles of utilizing gas pressures in practice, and on account of conflicting interests along property lines and other difficulties it may often be impossible to follow out these principles to their full logical conclusion, but even with such limitations the conservation of the natural energy offers considerable promise for increasing production. Because so little has been done to develop this phase of recovery, all that can be done in this publication is to review the principles and to suggest a few lines for experimentation in the field.

From the use of compressed air for increasing production, much valuable information may be derived that is applicable to the oil fields before the exhaustion of the gas. Heretofore it has been difficult to trace the underground movements of the oil and the gas and to connect cause with result, but in the Smith-Dunn process this can be done more readily and the effects of the passage of various volumes of a gas under different pressures can be noted for the different conditions found in the oil sands. Many of the principles disclosed by the practical operations of this process also apply to production by natural means, such as "by-passing," "blowing through," and other factors that cause inefficiency of expulsion. Though the operator will not have control over the source of energy as in the Smith-Dunn process, nor over the natural underground conditions, he will have some control over the efficiency of expulsion by regulating conditions at the producing well, and a study of how this is done in the use of compressed air will be of greatest aid.

use of compressed air benefits in a short time, usually within a few weeks, every well on a property, whereas flooding takes years for the water to spread from one well to the next, and only a few wells on a property are affected at one time. The quick benefits by air is an especially desirable feature in order to take advantage of a period of high prices. To apply water so as to affect all parts of the property, as compressed air is applied in the Smith-Dunn process, would lead to the trapping of large quantities of oil by the many convergent floods. Another considerable factor is that the flooded property is rendered practically valueless except for the equipment that may be recovered, and probably it will prevent the employing of any other process which might further increase the recovery of oil should they be discovered. On the other hand, the use of compressed air or gas leaves the property in such condition that flooding or any other process might be employed if it should be proved that they were more profitable. At this time, when it is by no means certain that recovery by flooding even under the comparatively favorable conditions at Bradford will be as effective and profitable as the use of air or natural gas, it would seem to be a short-sighted policy to use any process which would permanently damage the property until it has been demonstrated whether or not the use of compressed air or gas would be more beneficial.

MORE EFFECTIVE UTILIZATION OF NATURAL PRESSURES.

The recovery of oil may be divided into two stages: (1) The expulsion of the oil by the natural forces, and (2) the use of external forces after the natural forces have been virtually exhausted. So far only the second phase has been considered, but it is possible to increase recovery by more effective utilization of the natural gas found associated with the oil underground. Some information has been given on this subject by Huntley^a in Technical Paper 51, by Arnold and Garfias^b in Technical Paper 70, and by McMurray and the present author^c in Technical Paper 130. Discussion is limited here to increasing the so-called efficiency of expulsion, and the various mechanical devices for raising oil to the surface are not considered.

There is a definite and limited amount of natural energy associated with the oil in each field, and largely upon how effectively that energy is utilized to expel the oil from the sand will depend what

^a Huntley, L. G., Possible causes of the decline of oil wells and suggested methods of prolonging yield: Tech. Paper 51, Bureau of Mines, 1918, 82 pp.

^b Arnold, Ralph, and Garfias, V. R., Methods of oil recovery in California: Tech. Paper 70, Bureau of Mines, 1914, 57 pp.

^c McMurray, W. F., and Lewis, J. O., Underground waste of oil and gas, and methods of prolonging yield: Tech. Paper 130, Bureau of Mines, 1916, 28 pp.

records of properties in other fields there is reason to believe that the increased yields would last at least as long, and probably longer, than with water flooding.

BENEFITS FROM FLOODING AND FROM THE SMITH-DUNN PROCESS.

As the Smith-Dunn process is at the present time the only method yielding results that rival those of flooding at Bradford, comparisons are made between these two methods. Consideration must be given not only to the relative total recovery from flooding and other processes, but to the relative profits derived. One method might result in the recovery of a greater quantity of oil and yet the expense be so large that profits would be much less than for processes where the recovery was not so complete, and it would not be fair to the producer to expect him to employ a process where the recovery was larger but the profits disproportionately small.

Putting the water into the sand costs little or nothing, the only special equipment necessary, if any, being a casing or tubing between the water sand and the oil sand. It is the practice, when a flood is expected, to put old producing wells into thorough condition, which entails some additional expense, but it has been found necessary to drill at considerable expense many new wells spaced much closer than previously in order to protect the property lines or to prevent the passage of "flood oil" between the wells and to get the benefits within reasonable time. While the well is producing nothing but "flood oil" the current pumping costs are increased, but not the relative cost per barrel until the well begins to produce water, whereupon the cost rapidly increases until it becomes unprofitable to pump the well longer. For these reasons the actual expense of flooding may be considerably increased, though in the Bradford field this has been more than compensated by the increased yield. For example, a property with 16 wells affected by flooding showed in one month early in 1916 gross receipts for oil of \$1,951, with expenses of \$312.08, whereas another property with 14 wells and about the same acreage, a quarter of a mile distant, showed gross receipts of \$156.77 and expenses of \$83.45, this, however, being only the operating costs and not considering the cost of new wells, etc.

There are no data on which to make a close comparison of the actual cost of the use of compressed air, as compared with flooding, in the Bradford field, but from the data given on the use of the compressed air in other Appalachian fields it may be expected that the costs would not be much larger (exclusive of such royalties as may be paid for patent rights), and probably would be less than for flooding, considering that flooding requires drilling many new wells costing \$2,000 to \$3,000 or more apiece. Another factor is that the

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Maintaining back pressures on wasteful wells has been found to be the most effective way of overcoming the waste of air from bypassing in using the Smith-Dunn process. By this means air that otherwise would pass through the sand without doing much work is forced to take channels where it will move oil. Usually the daily yield of such wells is reduced, but sometimes it is found that the production of oil is actually increased. It is suggested that the principles embodied in the method of maintaining back pressures on the oil sand by a liquid seal, as shown in figure 4 (p. 45), could also be used advantageously on wells before the supply of natural gas has been exhausted, in order to prevent the wasteful escape of gas beyond the amounts that would expel the oil most efficiently. The benefits may be considered to extend beyond the well itself, for one well may waste much gas that otherwise would contribute to the production of other wells on the property.

Quick^a has made some interesting observations on the effects of letting water stand in the hole while the wells were being drilled through the oil sands and during the periods of flush production. Because of the lack of effective ways of excluding water, most of the wells in the early fields in Pennsylvania had water standing in the hole when drilled and Quick observes that such wells produced more oil than has been the case since the practice has been to drill the wells in dry. The column of water in the hole provided a liquid seal that prevented the excessive escape of gas and consequently more of the energy was used in expelling oil from the pores in the sands. Moreover, the water prevented to a large extent the lowering of temperatures from the expanding gas and the vaporization of the gasoline in the oil which would have caused the deposition of paraffin and waxy sediment in the pores of the sand.

The following method, described in Technical Paper 130,^b was first applied to gusher wells in California that, if allowed to flow unrestricted, would "sand up" or be likely to get beyond control:

In some of the California fields wells capable of producing as much as 10,000 to 15,000 barrels of oil a day, and making in addition several million feet of gas, are restricted to a flow of 1,000 barrels a day or less, with a comparatively small flow of gas, by closing the well to a five-eighths-inch or one-inch opening. It has been found that the ultimate flush production from such restricted wells has almost invariably been more than the unrestricted flow from neighboring wells.

It is necessary to experiment on each well to find the size of opening for best results and from time to time this must be changed as conditions change at the well. If the opening is too small only gas

^a Quick, M. W., *Has Pennsylvania 370 years of oil left?*: Nat. Petroleum News, vol. 5, October, 1913, pp. 1-3, and following issues.

^b McMurray, W. F., and Lewis, J. O., *Underground wastes in oil and gas fields, and methods of prevention*: Tech. Paper 130, Bureau of Mines, 1916, p. 17.

may be let through. The method is applicable only to some flowing wells, and about the same results have been obtained by maintaining back pressures through gas-separating traps. The effect on the rate of production is variable; in some cases considerable back pressure may be held on the well without materially diminishing production. The saving of vapors in the gas traps has in a number of instances increased the yield of oil.

Though it has not been established definitely, there is reason to believe, from experiments and from experience with the Smith-Dunn process, that there are pressures of maximum efficiency above which energy will be wasted in expelling the oil by gas or air. The natural pressures found in an oil well may be above this most efficient pressure, and in such a case it seems possible that efficiency may be increased by maintaining back pressure on the well. The maximum pressure will vary from well to well and during the life of each well, and what back pressure to hold can be found only by trial and by gaging the relative volumes of gas to oil. In a flowing well in California it was found that a certain back pressure not only decreased the relative volume of gas to oil, but actually increased the yield of oil.

One of the most obvious wastes of energy is in wells where the top of the productive sand carries gas only. If the gas in this part of the formation is not restrained, it will escape rapidly and diminish the pressure quicker than in the oil-bearing part of the sand, and is likely to become a by-pass channel into which gas given up from the oil sand will be fed and its energy wasted without doing its quota of work. Furthermore, the flow of gas into this part of the sand is likely to carry oil with it, much of which will be retained in the pores and can not be recovered. A noteworthy instance is reported from the Cushing field, Oklahoma.* It has often been the practice not to separate the gas-bearing from the oil-bearing parts of the formation in order to aid the flow of oil, but the benefits, if any, are temporary and in the long run it would pay to separate the gas from the oil by casing or packers, that the gas may find exit only through the oil-bearing part of the sand and aid in expelling the oil rather than to become a means of wasting gas and decreasing recovery.

* McMurray, W. F., and Lewis, J. O., *Underground wastes in oil and gas fields, and methods of prevention* : Tech. Paper 130, Bureau of Mines, 1916, p. 18.

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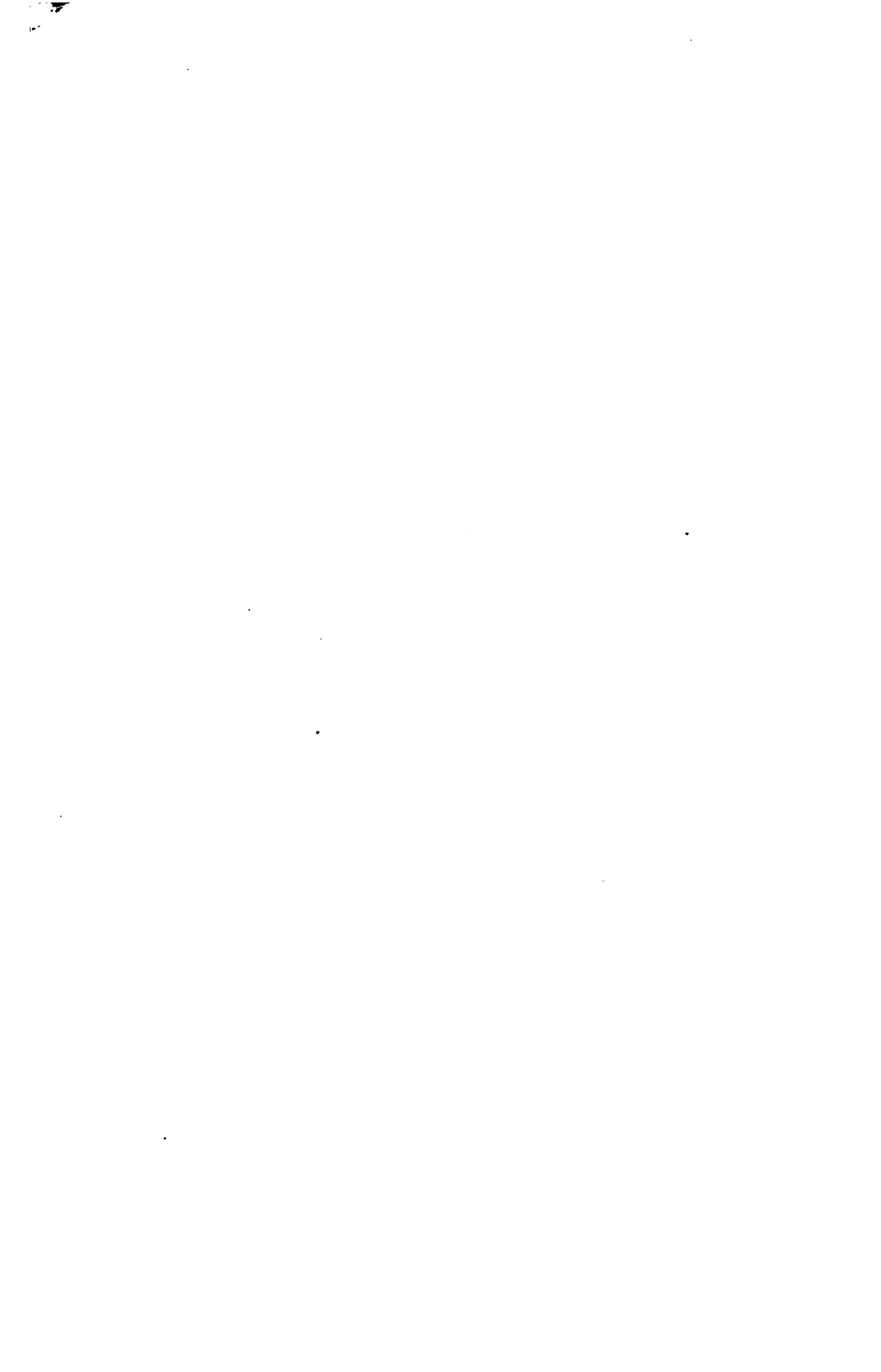
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DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

**ELECTRODEPOSITION
OF GOLD AND SILVER FROM
CYANIDE SOLUTIONS**

BY

S. B. CHRISTY



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The Bureau of Mines, in carrying out one of the provisions of its organic act—to disseminate information concerning investigations made—prints a limited free edition of each of its publications.

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ELECTRODEPOSITION OF GOLD AND SILVER FROM CYANIDE SOLUTIONS.

By S. B. CHRISTY.

INTRODUCTION.

This report on the electrodeposition of gold and silver from cyanide solutions represents work that has occupied my time at intervals during the past 20 years. The investigation has been carried on simultaneously with my duties as professor of mining and metallurgy of the University of California.

During this long investigation I have been assisted in the details of the work by a number of my former students, acting in turn as assistants. Particular mention in this connection is due W. H. Hilton, who graduated in 1900; C. T. Dozier, 1902; N. C. Stines, 1905; H. N. Herrick, 1907, and L. C. Uren, 1911.

It is impossible to publish full details of the many thousands of experiments performed. Effort has been made to present only the essential data. Wherever possible, the results of the experiments have been expressed in diagrammatic form by curves showing the relation between the simultaneous variables of the experiments.

It is necessary to show, as nearly as may be, the state of the art. This is difficult because of the meager literature on electrodeposition in the cyanide process; hence resort must be had to the specifications and claims of patents, most of which seem never to have been applied on a working scale. Such information consequently can not be taken at its face value. Expressing the essential ideas evolved in such specifications is no easy task. Clearly, in quoting from patent records it is not feasible to enumerate all of the specifications or the claims allowed the inventors. A statement of the chief contributions to the art in the patent cited must suffice. Legal details, of course, must be obtained from the original patent.

In the study of patent literature, when one compares the ardent hopes of the inventors with the results realized from their efforts, it becomes clear that in the development of an art no one man con-

tributes everything. Each subsequent inventor stands on the shoulders of the one who has gone before. It is only through the summation of the contributions of many inventors that the art as a whole prospers.

On October 19, 1887, a British patent was granted to McArthur and Forrest for the use of dilute cyanide solutions for treating gold and silver ores. The rapid extension of this process, in various forms, all over the world, has almost revolutionized the treatment of ores containing precious metals. It is a remarkable fact, however, that long before this patent was granted there was issued, on February 5, 1867, to J. H. Rae, U. S. patent 61866, for an electrocyanide process. Thus a method of electrodeposition from cyanide solutions used for treating ores was invented 20 years before the McArthur and Forrest patent was granted, although the process did not come into general use.

On May 24, 1889, U. S. patent 403202 was granted to McArthur and Forrest for the use of zinc shavings for removing gold and silver from cyanide solutions. The use of finely divided zinc is still the standard method for recovering gold and silver from cyanide solutions. Since this patent was granted, many attempts have been made to replace the precipitation upon the zinc by methods of electrodeposition. It is the purpose of this report to give an outline of some of these methods, as well as to show the relative advantages and disadvantages of the zinc and the electrical methods of recovering gold and silver from cyanide solutions.

PROCESSES OF ELECTRODEPOSITION.

Processes of electrodeposition may be divided into two classes, according as the action takes place, in the presence or in the absence of the pulverized ore itself.

ELECTRODEPOSITION IN THE PRESENCE OF THE ORE PULP.

All the processes of this type hitherto invented require keeping the ore pulp in motion by mechanical agitation. This is necessary, because otherwise the electrical resistance would be too great and because the metal would be deposited in filamentary form between the ore particles and would be difficult to recover.

PATENTED PROCESSES.

The first of these processes was that of J. H. Rae, previously mentioned. The patent discloses the treatment of pulverized ore in a vessel containing the ore together with a solution of cyanide of potassium. In the vessel was provided a metallic agitator which acted as

an anode and kept the ore in suspension. The gold and silver were precipitated on a plate cathode suspended in the solution above the anode. Some time in the seventies a number of experiments were made with such a process in a modified form in San Francisco with ores from Virginia City. The experiments were conducted in an amalgamating pan, the agitator being connected with one pole of the battery and the quicksilver with the other pole. When these experiments were made, it is reported that an alternating current was used, although the inventor expressly states that a direct current should be used. The results obtained were claimed to be slightly better than those with plain amalgamation, but were not enough better to warrant continuing the process.*

On November 3, 1891, a patent (U. S. patent 162535) was granted to the celebrated Prof. William Crookes, of London. This patent was for an electroamalgamation process, by which the ore was to be suspended in a solution containing a soluble salt of mercury, such as sulphate, nitrate, or cyanide. The patent claimed that when suspended ore was submitted to the action of an alternating current of electricity the gold was rapidly amalgamated. I do not know whether this process has ever been tried commercially, but from my own incomplete study of it I do not think that it is likely to be successful. Other and more recent patents are the following:

H. F. Edwards, U. S. patent 518543, April 17, 1894.—An amalgamating device consisting of a vessel containing carbon anodes and mercury cathodes. The solution consists of cyanide of potassium and ferrous oxide. The use of ferrous oxide with cyanide is enough to put this process out of consideration.

Paul Danckwardt, U. S. patent 526099, September 18, 1894.—A process for extracting gold and silver from ores. The appliance consists of concentric drums, either the outer or the inner one of which is made to revolve, either the outer or the inner serving as an anode or a cathode. The suggested use of alkaline sulphide in connection with cyanide of potassium seems entirely out of place; and no better mechanical devices could be found for scouring the precipitated metal from the cathodes.

Pelatan and Clerici were granted three United States patents as follows: No. 551648, December 17, 1895; No. 553816, January 28, 1896; and No. 568099, December 22, 1896. These patents all disclosed cast-iron or steel agitators which acted as anodes, and amalgamated copper plates or a bath of mercury which served as the cathode. They differed from one another merely in the mechanical disposition of the agitator. The first patent showed an agitator of horizontal axis, the second one of vertical axis. The agitator described in the

* Julian, H. F., and Smart, Edgar, Cyaniding of gold and silver ores, 1904, p. 143.

bird comprised a belt made of steel with attached arms, so that when the belt was moved by rollers, the stirrers were carried over the surface of the mercury so as to agitate the pulp continuously, the operation being carried on in the presence of a cyanide solution. Experiments on a working scale with this process were conducted by J. B. Huntley in the Delamar mine, in Idaho, and I learn from him that extractions of more than 80 per cent were obtained; but I understand that none of these methods is now in use. The chief objections were the large amount of power used in fine grinding, and the scouring of the cathode. The process was replaced by cheaper washing methods.

E. Motz, U. S. patent 582077, May 4, 1897.—This covers an electrolytic, rotated drum. The ore and pulp are mixed.

B. Becker, U. S. patent 588740, August 24, 1897.—The appliance consists of a conical tank for agitation from below by a centrifugal pump. A part of the overflow passes into a cylindrical tank having conical bottom and containing radial or concentric vertical anodes and cathodes. The coarse gold is supposed to be amalgamated upon the sides of the first or agitating tank, and the dissolved gold, electrically precipitated, is recovered in the second tank. Circulation is controlled by suitable valves so that only the finest material passes over to the second tank for electrodeposition.

H. S. Badger, U. S. patent 635544, September 19, 1899.—Electroamalgamating barrel.

L. E. Porter, U. S. patent 639766, December 26, 1899.—Electro-tic barrel.

C. P. Tatro and George Delius, U. S. patents 640717 and 640718, March 27, 1899.—Apparatus and process.

W. Witter, U. S. patent 641571, January 16, 1900.—Cyanogen chloride produced by electrolysis used later with pulp.

N. L. Turner, U. S. patent 653538, July 10, 1900.—Concentric electrodes in tank.

A. J. Irwin, U. S. patent 689674, December 24, 1901.—An endless metallic belt, as anode, supporting the pulp. The cathodes are above.

H. R. Cassel, U. S. patents 694349 and 694350, March 4, 1902.—Process and apparatus. The process comprises electrolysis of the pulp with salt, followed by the use of cyanide, to extract gold and silver.

F. T. Mumford, U. S. patent 706436, August 5, 1902.—The pulp contained in an amalgamating cylinder of copper-lined steel. The electrodes are of carbon.

W. H. Adams, jr., U. S. patent 745742, December 1, 1903.—A tank provided having a conical bottom and an agitating device. No claims are made for any electrolytic device, but one is disclosed in the

specifications. On account of the lack of proper means for circulating the electrolyte between the inclined electrodes the process would probably be ineffective.

Ernest A. Fahrig, U. S. patent 756223, April 5, 1904.—A complicated system of agitating pulp in a series of inclined electrodes placed in a tower down which the muddy solution falls. The construction is such that an electrically efficient process seems impossible, scouring and other interferences being sure to take place. An apparatus so arranged is not easily constructed or adjusted.

E. L. Oliver, U. S. patent 784120, March 7, 1905.—An apparatus for cyanide-pulp treatment. A cylindrical tank having a conical bottom contains vertical cathodes of copper plate in electric contact with a horizontal tube containing mercury, in such a manner as to allow the mercury to spread by diffusion over the plate as the gold and silver amalgam form upon it. The anodes first specified were $\frac{1}{8}$ -inch sheet-iron plates, but these were afterwards changed to rods of Acheson graphite. The pulp was agitated by compressed air which entered at the center of the conical bottom and forced the ore up through a central pipe, causing it to spread out in the solution and fall between the electrodes. This process was introduced on a working scale at the North Star mine in 1903 and was continued in use there until 1906, during which time more than \$200,000 in bullion was recovered at a profit.^a The gold amalgam was recovered in a stronger cyanide solution by changing the cathodes into anodes (after U. S. patent 643096, S. B. Christy). The process gave good results for the treatment of low-grade tailings. An actual recovery of about 75 per cent was claimed. The difficulty in the operation of the process was that the copper plates and the quicksilver held back valuable metal. There was also considerable gold left on the anodes, particularly when the anodes were of iron. Many of the anodes assayed \$70 per ton, and even as high as \$200 per ton. Probably, also, there was a considerable loss of quicksilver. The Acheson-graphite anodes worked very well with tailings; but when an attempt was made to treat sulphide concentrate, sulphates formed and rapidly oxidized the graphite rods which soon were converted into a black mud. As long as sulphates were absent the rods were hardly acted upon. The process of precipitation at the North Star mine has since been replaced by C. H. Merrill's zinc-dust process.

W. A. Hendryx, U. S. patent 785214, March 21, 1905.—An apparatus for the extraction of metals from ores. The apparatus disclosed in the patent shows a vertical cylindrical tank with a conical bottom containing a central tube, in which is placed a revolving screw agitator which discharges the pulp in a continuous stream at the

^a Swaren, J. W., Historical notes on the air-lift agitator: Min. and Sci. Press, vol. 103, Sept. 30, 1911, pp. 410, 411.

top over a slightly conical deflecting apron so as to expose the pulp in a thin film to the action of the air. The pulp then descends through a series of electrodes inclined at a slight angle. The anodes are of carbon and the cathodes are of thin sheet lead.

W. A. Hendryx, U. S. patent 836380, November 20, 1906.—An ore-treating process which incidentally required the electrolytic apparatus previously described. The process was introduced in a number of places, but to the best of my knowledge the electrical part has been abandoned and the apparatus is now in use only as an agitator.

J. A. Comer, U. S. patent 833999, October 23, 1906.—A patent applying chiefly to the handling of pulp by compressed air. The electrical part of the device embraces nothing novel.

E. J. Garvin, U. S. patents 809939, January 16, 1906, and 822940, June 12, 1906.^a—The apparatus consists of a cylindrical agitator having a conical bottom and containing a small, inverted, floating cone in the center and a small funnel-shaped hopper at the top. The pulp is made to circulate by a centrifugal pump from the bottom of the conical tank over a series of amalgamation plates, electrically connected, which are employed for amalgamating any coarse gold. The pulp then flows through the hopper, down through the agitator, and back through the pump.

The upper part of this apparatus contains nearly clear water that has been allowed to by-pass over the top of the agitator to the electrical precipitation device, which is contained in a rectangular box with a cylindrical bottom. At the bottom of the cylinder is placed a small quantity of quicksilver; and two anodes of sheet iron are connected on either side of the cathode. This cathode consists of a link belt, made of horizontal copper strips, which moves slowly with its lower end submerged in quicksilver, thus keeping the surface amalgamated. The solution passes underneath the first anode, up through the lattice belt cathode, and thence down and out. By means of suitable valves, clear or nearly clear water passes through the precipitation tank. The coarse gold is supposed to be caught on the amalgamated copper plates on the top of the box, and the dissolved gold on the copper-belt cathode of lattice work.

Actual working results by this process are not given in the description, and seemingly it would be difficult and expensive, with this apparatus, to get sufficient area for effective precipitation. Whether it would be possible to prevent mechanical loss, either of the quicksilver or of the gold, from the cathode is perhaps questionable, especially as the descriptive circular states that the liquor flowing into the precipitation box is not always clear, but is usually somewhat turbid. The company at Portland, Oreg., formed for operating the process is said to have abandoned it.

^a Garvin Cyanide Extraction Co., Bull. 2, 1906.

DIFFICULTIES OF RECOVERING GOLD AND SILVER FROM CYANIDE SOLUTION
IN PRESENCE OF ORE PULP.

The idea of recovering gold and silver from cyanide solutions in the presence of the ore pulp appears at first sight attractive, as it offers a means of doing away entirely with the great difficulties of filtration and decantation; but all processes founded on this idea have to overcome other obstacles. The first difficulty is that the electrical resistance of a bath containing a large number of non-conducting particles, such as quartz, is greatly increased over that of a clear solution. A second is that the deposited metal is rapidly stripped from the cathodes by the scouring action of the moving ore particles. Such mechanical abrasion causes serious loss. When the cathodes are of mercury or amalgamated copper, a third difficulty results from the surface tension of the mercury.

I contended with this difficulty in experiments made in June, 1889. In these experiments I used as an anode a platinum dish containing roasted pyritic ore that assayed 3.38 ounces gold and 2.63 ounces silver. The dish contained, besides the ore, a 10 per cent solution of cyanide of potassium. The battery used consisted of several dry cells, and the current was 3 milliamperes. The time was 20 hours. I found that a loosely adherent black film formed on the amalgamated copper cathode. The film was easily shaken off into the ore below. The extraction, by difference, was 86.7 per cent. I repeated the same experiment the next day, using as before a platinum dish as an anode, with a 10 per cent solution of cyanide of potassium, and above the ore I placed a small flat porcelain dish (diameter 40 mm.) containing mercury, into which was inserted a graphite rod connected with the negative pole of the battery. The gold and silver and a little copper came down on the mercury in little hair-like particles of about the size and shape of the upper part of an exclamation point (!). They stood all over the surface of the mercury in an erect position like quills on "the fretful porcupine," being buoyed up by bubbles of hydrogen; and owing to the surface tension of the mercury amalgamation of these particles was difficult. Violent agitation would sweep the particles completely away from the mercury surface, whereas gentle agitation would sometimes cause them to amalgamate.

The experiments demonstrated that there are serious difficulties connected with recovering gold and silver from cyanide solutions in the presence of the moving ore pulp. Although a fairly good recovery by the method mentioned is not impossible, a really satisfactory method has not yet been devised.

In confirmation of these views the experiments of Rose^a may be quoted. Rose found that with cathodes of mercury or amalgamated copper, and with a current density greater than 0.01 ampere per square foot, a part of the gold came down as a black scum floating on the surface of the cathode in such a form that it could be brushed off with a feather. In the successful experiment with amalgamated copper cathodes there were used 0.7 volt, 0.01 ampere per square foot, 0.082 per cent KCy, and a gold content of 20 ounces per ton. With a lower density the plate remained bright, but the precipitation was extremely slow. In one test, in which mercury alone was used, and with a density ranging up to 0.027 ampere per square foot, less than 1 per cent of the gold appeared in the form of the black scum. With denser currents fully half the gold came down in the form of this scum, which could not be amalgamated except by the use of sodium amalgam. When amalgamated copper was used as the cathode, the copper dissolved in the cyanide, in spite of the current, and caused the destruction of cyanide. Hence, in view of the high cost of mercury and copper, and the difficulty of removing the gold from the copper, the methods requiring mercury or amalgamated copper as cathodes do not seem to have a bright future.

ELECTRODEPOSITION OF GOLD AND SILVER FROM CLEAR CYANIDE SOLUTIONS.

Clear solutions are obtained by either decanting or filtering the ore-bearing solutions, so that only clear solutions containing gold, silver, and possibly other metals, as double cyanides, have to be treated. In spite of the difficulties and expense of decantation and filtration, these steps seem to be necessary for satisfactory results with either electric precipitation or zinc precipitation. However, before going into a critical study of methods, two questions should be answered, namely, What is the valency of gold in cyanide solutions? At what voltage are metals best precipitated from cyanide solutions?

VALENCE OF GOLD IN ELECTROLYSIS OF CYANIDE SOLUTIONS.

It is generally admitted that the gold in cyanide solutions from ore treatment is monovalent, as KAuCy_2 , but there seems to be a general assumption that in electrolysis gold is always trivalent. In Foster's electrical engineer's pocketbook^b the atomic weight of gold is wrongly given as 195.7, and that of silver as 107.11. Gold is plainly stated to be trivalent, and the amount precipitated per ampere-hour is given as 2.4512 grams, and the amount of silver precipitated per ampere-hour is given as 4.0248 grams.

^a Rose, T. K., The electrical precipitation of gold on amalgamated copper plates: *Trans. Inst. Min. and Met.*, London, vol. 8, 1900, p. 389.

^b Compiled by R. S. Woodward, jr., and G. S. Miller, jr., 1910, p. 1230.

Roeber^a does not commit himself on the valence of gold, but gives the reader a free choice among three values. Roeber's article is one of the best short statements of modern electrochemical theories. His data in regard to silver and gold are as follows:

Atomic weight of silver, 107.93; valence 1, ampere-hour 4.025 grams.

Atomic weight of gold, 197.2; valence 3, ampere-hour 2.451 grams; valence 2, ampere-hour 3.677 grams; valence 1, ampere-hour 7.35 grams.

"Hütte." Taschenbuch für Eisenhüttenleute (1902 edition) gives for silver: Atomic weight, 107.7; valence 1, ampere-hour 4.0269 grams. The values for gold are: Atomic weight, 196.2; valence 3, ampere-hour, 2.4453 grams.

Steinach and Buchner^b give the following values: Silver, monovalent, ampere-hour 4.026 grams; gold, trivalent, ampere-hour 2.445 grams.

Keith^c says that gold is trivalent in cyanide solutions.

According to the International Atomic Weights Committee^d the atomic weight of silver is 107.93, with a possible error not greater than ± 0.01 , and the atomic weight of gold is 197.2, with a possible error not greater than ± 0.1 . These values being assumed to be correct, if gold is monovalent, for every grain of silver precipitated by a given current 1.837 grams of gold should be precipitated by the same current, and if gold is trivalent, for each gram of silver precipitated there should be precipitated only 0.612 gram of gold.

Of course gold is capable of reacting in at least two cyanide compounds— KAuCy_2 and KAuCy_3 —the former of which is monovalent and the latter trivalent. In estimating the electrical efficiency of cyanide precipitations, it is absolutely necessary to know which of these values to choose for the reactions that take place. To investigate this matter I prepared three separate solutions, as follows: No. 1 containing 250 mg. of silver as nitrate, No. 2 containing 250 mg. of silver as KAgCy_2 and 150 mg. of free KCy , and No. 3 containing 100 mg. of gold as KAuCy_3 and 150 mg. of free KCy . The anodes and cathodes in solutions 1 and 2 were both of pure silver. In solution 3 they were of pure gold. Three cells were thus set up in series with a storage-battery cell of 2 volts, and after a period of 1 hour and 50 minutes all the electrodes were weighed. The following results were obtained:

^a Roeber, E. F., Standard handbook for electrical engineers, 1908, 1,285 pp.

^b Steinach, Hubert, and Buchner, Georg, Die galvanischen Metallniederschläge, und deren Ausführung, Berlin, 1890, 258 pp.

^c Keith, N. S., Electrolysis of gold: Jour. Inst. Elec. Eng., vol. 24, 1895, pp. 236-260.

^d Clarke, F. W., Seubert, K. E., and Thorpe, J. E., Report of the International Committee on Atomic Weights, 1903, p. 5.

Experiment 1. The anode (A) lost 45.23 mg., and the cathode (B) gained 43.22 mg. The silver came down in fine crystals, and a small proportion of these was unavoidably lost in weighing, which accounts for the low value obtained.

Experiment 2. The silver anode (C) lost 45.12 mg., and the cathode (D) gained 43.78 mg.

Experiment 3. The gold anode (E) lost 81.52 mg., and the cathode (F) gained 76.69 mg. It will be noticed that the gain in each test was slightly less than the loss, even in experiment 1, in which there was mechanical loss in weighing the cathodes.

Let us compare the gain of the gold cathode F with that of the silver-nitrate cathode B. Dividing F by B, we have 1.774, and comparing the gain of the gold cathode F with that of the silver cathode D, both values being in cyanide of silver, we have $\frac{F}{D} = 1.75$.

However, as there might be a slight loss in weighing the cathodes, it might be nearer the truth to compare the losses of the anodes rather than the gains of the cathodes. First let us compare the gold loss from anode E with the silver loss from anode C, both in cyanide solutions. If we divide E by C the quotient will be 1.807 instead of 1.837. Supposing the metal to be monovalent, if we divide E by A we have 1.802 instead of 1.837.

It must be evident therefore that in aurocyanide of potassium solutions the gold acts practically as a monovalent metal. That less gold is precipitated than is dissolved in cyanide solutions is probably due to the presence of free cyanide of potassium. It is necessary however to have a certain excess of cyanide, as if there is no excess, AuCy_2 forms on the anodes.

Iron is sometimes trivalent and sometimes bivalent, and it is possible that similarly gold may be both monovalent and trivalent. It is well known that gold does exist as potassium auricyanide, but it appears that the aurocyanide salt is much more stable, the auricyanide tending to break down into the aurocyanide. However, there seems to be no reasonable doubt that in estimating the electrical efficiency in precipitation processes the gold should be considered as monovalent.

VOLTAGES AT WHICH THE METAL IS COMPLETELY PRECIPITATED FROM CYANIDES.

This is a subject about which little has been published. Friedenberg^a claims that the precipitation is as follows:

K_2HgCy_4 , complete at 1.6 volts.

KAgCy_2 , complete at 1.7 to 1.8 volts.

^a Friedenberg, Ztschr. Phys. Chem., Bd. 12, 1891, p. 97.

KAuCy_2 , complete at 1.9 volts.

K_2CuCy_4 (with $\frac{1}{2}$ to 1 part KCy) at 2 volts.

KCuCy_2 (with 10 to 15 parts KCy) at 2.5 volts.

Some precipitation is possible at lower voltages than these. Theoretically, complete precipitation would require an infinite voltage, but what is meant by the author quoted is precipitation sufficiently complete for quantitative purposes. From my experience I consider the voltage given for copper entirely too low. Experience shows that much depends on the amount of free cyanide and other salts present.

The figures cited are to be regarded only as lower limits. The author states that the precipitation is slow at these voltages and prefers to use 2.5 volts for gold. The figures explain the low results obtained in the experiments with the Keith process in which an average voltage of only 0.75 was used.

SIEMENS & HALSKE PROCESS.

In 1888 Wernher von Siemens first applied for patents (Heirs of E. W. von Siemens, U. S. patent 601068, Mar. 22, 1898) for his process of electrical precipitation which seems not to have been introduced on a working scale until 1893. The process had previously been patented in the Transvaal under date of July 7, 1892, patent 397. The patent covers both the method and the apparatus, according to the patent laws then in force. The precipitation method claimed is as follows: "A method of extracting gold from a weak cyanide solution, which consists in circulating the solution over anodes of iron and cathodes of lead. Said cathodes being formed of thin plates arranged at short distances apart, and have from 9 to 10 square feet of surface for each ton of solution in contact with them. Said solution while in motion is subjected to an electrical current of from $3\frac{1}{2}$ to 4 volts and 0.5 to 1.5 amperes per square meter of cathode surface substantially as set forth." It will be observed that the claims allowed are not general but are much restricted in their nature.

The Siemens process was first introduced in South Africa through the agency of Charles Butters, and although the patent shows a centrifugal pump as the means of continuously circulating the solution through the deposition box, this was soon abandoned and the process was applied by constructing long boxes to allow the gold and silver to be deposited sufficiently by a single flow through the box. The anodes were of iron, and were placed 3 inches from the cathodes, which were made of thin strips of lead. As soon as 2 to 12 per cent of the gold, or on an average 7 to 8 per cent, had been deposited on

the lead cathodes, the lead strips were taken out from the cells, melted down, and cupelled.

This process, popularly known as the "Siemens & Halske process," was used for a long time in the Transvaal in competition with precipitation by zinc shavings, and was fairly successful there under the management of Mr. Butters. However, after he left the Transvaal, the method was gradually replaced by precipitation by zinc shavings, the latter method having been greatly improved. For some time the Siemens & Halske process has been substantially abandoned in Africa. In a modified form, mentioned later, electrical precipitation is still used by Mr. Butters in several of the mines under his management.

One difficulty with the Siemens & Halske process was the large size of the box necessary for effective precipitation. Mr. Butters told me that when he first constructed the cells some of his English friends asked, "Are you constructing stalls for horses?" The cells were large enough to have been used for that purpose. One of the reasons for the large size was the necessity of avoiding short circuits. These were liable to be encountered owing to the fact that the anodes, in the presence of sulphates and chlorides, contained in the solution, soon became coated with warty growths of hydrate and hydrated carbonate of iron and prussian blue. Hence a 3-inch space was left between the anodes and the cathodes. The maximum daily capacity was not usually more than 5 tons of solution treated to each box holding 1 ton of solution, and the volume treated was usually much less.

There have been many descriptions of the Siemens & Halske process, but most of them omit some detail necessary for calculation of the electrical efficiency. The most complete description of the essential details of the process that I have been able to find is that by Richards.*

There were four deposition boxes, each 30 feet long by 4 feet 9 inches wide and 3 feet deep. Each box contained 110 iron anodes and 110 cathodes formed of bags containing 5 to 10 pounds of lead shavings the extent of the surface of which is problematical. The tanks were electrically coupled in series, 2.5 volts being required for each. The current was 200 amperes. Each box held about 14 tons of solution, or, allowing for the electrodes, 10 to 12 tons, so that the capacity of a box holding 1 ton of solution would have been 4 to 5 tons a day. The heads assayed 80 and the tails 15 grains gold. Hence, only about 81.5 per cent of the gold content, weighing 3,250 grains (0.464 pound or 0.21 kilogram), was precipitated at this rate of flow per day. Prof. Richards comments as follows:

That this is an insignificant amount for the current passing (200 amperes), which should theoretically deposit 34.56 kilograms in each box, is patent to the

* Richards, J. W., The cyanide process for the treatment of gold ores: *Jour. Franklin Inst.*, vol. 143, February, 1897, p. 96.

electrometallurgist, the yield being only 0.6 per cent, but it must be remembered that the extraordinarily dilute solution used will not yield up its gold any faster and that it must be electrolyzed slowly to get any sort of correspondence between the power used and the gold obtained.

Under the conditions of the Siemens & Halske process this statement is true, but, as shown later, under the right conditions better results can be obtained.

If we assume as correct that 7.35 grams of gold should be precipitated in 1 ampere-hour, it follows that 200 amperes should precipitate 1,470 grams each hour, or in 24 hours there should have been precipitated 35.28 kg. instead of 0.21, showing that the efficiency was only 0.59 per cent, which is essentially the same as that of Prof. Richards, who seemingly used a different constant. The gold recovery also is rather low, there being a reduction only from \$4.26 to \$0.64 per ton.

Julian and Smart's excellent book,^a giving details of the Siemens & Halske method of electrical precipitation, has been carefully examined to see whether it presented data that could be used in calculating the electrical efficiency of the process. Although Table 31 contains 18 columns of data, it is not complete enough for a reliable calculation of the electrical efficiency.

However, by making some assumptions, approximations may be possible.

Thus a high precipitation is cited as being obtained at the Croesus works where seemingly the gold content is said to be reduced from 48 grains to a trace. However, the authors do not state the current density per square foot of cathode surface, but it probably was not higher than that cited for other operations, namely, 0.04 ampere per square foot. Only one precipitation box, containing 38.8 tons of solution, was used, 50 tons being treated in 24 hours. On the basis of a 1-ton box the rate would be 1.29 tons of solution per 24 hours. The cathode area is given as 7,680 square feet. If we assume the current density to be 0.04 ampere per square foot we shall have 307 amperes, or 7,368 ampere-hours, a day. Precipitation should then be at the rate of 7.35 grams of gold per ampere-hour, or 54.155 kg. of gold. The heads are said to have contained 48 grains and the tails a trace. If we assume all of the gold, 48 grains per ton, to have been precipitated, the recovery for the 50 tons of solution would be 2,400 grains, or 0.156 kg. of gold actually precipitated. Dividing 0.156 by 54.155 gives only 0.288 per cent as an electrical efficiency. Hence, although the recovery is rather high, the capacity per ton of box capacity is only 1.3 tons of solution a day, and the electrical efficiency is less than 0.3 per cent, which is one-half that calculated by Richards.

^a Julian, H. F., and Smart, Edgar, Cyaniding gold and silver ores, 1904, p. 143.

The figures as presented by Julian and Smart for the May Consolidated plant may next be considered. Two results are given—the one covering the solution coming from the sand tank, and the other covering the solution from the slimes. In the sand tank 6 boxes were used, containing 133.2 tons of solution. These treat 300 tons a day. Consequently the capacity on the basis of a 1-ton box is 2.25 tons a day. The cathode surface is not given. If we assume it to be the same as the anode surface, 13,824 square feet, with a current density of 0.04 ampere, we shall have a total of 553 amperes, or in 24 hours, 13,271 ampere-hours. This current should precipitate 97.542 kg. of gold. As a matter of fact the head solution assayed 120 grains of gold per ton and the tail solution 18 grains, or there was precipitated 102 grains per ton. For the 300 tons, with the weights converted to kilograms, there was precipitated 1.982 kg. of gold, or the electrical efficiency was 2.03 per cent, according to the data given and the assumptions here made. But it is altogether probable that the cathode surface was much larger than that of the anodes. Hence the efficiency would be much less than that stated. The precipitation is rather high, being over 93 per cent, but the capacity is low, being one-half of what I obtained with my experiments at Bodie.

Considering the May Consolidated slime plant, we find that the solution was treated in four boxes, containing 181 tons, in which 320 tons was treated each day. At this rate a 1-ton box would have a capacity in 24 hours of 1.73 tons, a lower rate than was obtained from the sand solution. There was 16,892 square feet of anode surface. The cathode surface is not given, but was probably larger than that of the anode surface, and if the surface of each be assumed to have been the same, with a current density of 0.04 ampere, the daily current of 16,220 ampere-hours thus obtained should have precipitated 119.22 kg. of gold. As a matter of fact the head solution contained only 24 grains of gold and the tail solution 2.4 grains. There was actually recovered, per ton, 21.6 grains of gold, or, from 320 tons there was precipitated 0.448 kg. of gold. This when divided by 119.2 gives only 0.376 per cent electrical efficiency. If, as is probable, the cathode surface was larger than the anode surface, the electrical efficiency would be still lower.

MOLLOY PROCESS.

The following description of the Molloy process is taken from Julian and Smart:*

This process was patented in the Transvaal in 1892 by B. C. Molloy, where it was employed for some months. It consists in passing the gold-bearing solution over a surface of mercury in which sodium was continuously deposited.

* Julian, H. F., and Smart, Edgar, Cyaniding gold and silver ores, 1904, p. 158.

An ingeniously devised apparatus was employed which consisted of a large shallow tray covered with mercury, down the center of which was a narrow compartment, with sides that dipped slightly into the mercury. In this compartment was placed a strong solution of sodium carbonate which was electrolyzed, the mercury at the bottom being the cathode, and the anode was of peroxidized lead. As the sodium deposited and accumulated in the mercury within the compartment it diffused to the mercury on the outside, over which a constant stream of gold-bearing solution was kept flowing. The gold-bearing molecules dissolved as they came in contact with the sodium amalgam surface, were decomposed, and gold amalgam formed.

The process was ably developed by Dr. A. Simon, who employed it on a working scale in the treatment of tailings on Witwatersrand in 1892-93.

The weak point of the the process lies in the difficulty of getting a sufficiently large electrode surface for the solution to come in contact with, without unduly increasing the amount of mercury handled. Thus, if the area of a surface required to reduce a 5 dwt. solution down to 1 dwt. was 1, that to reduce a 1 dwt. solution down to 5 grs. would have to be somewhere about 25 with the same rate of flow, showing how enormously the area has to be increased as the solution becomes impoverished. This difficulty may, however, be got over, to some extent, by agitating the solution rapidly over the sodium amalgam surface as it flows, by mechanical means. The efficiency of sodium amalgam as a precipitant is small, but when employed in a dilute state, as in the Molloy process, it compares favorably with the electrical precipitation processes of to-day. Sodium amalgam is said to act on KCy in solution forming complexes, but in dilute working solution this action is inappreciable.

I have obtained good precipitation by this method so long as the capacity was limited, but the moment it was pushed, the extraction fell off. Of course, all the objections to the use of mercury apply. The process seems to have been abandoned.

VARIOUS OTHER PATENTED PROCESSES.

Johannes Pflieger, British patent 16737, September 6, 1895.—The inventor uses cathodes composed of shavings, wire, powder, or shot and presenting a large surface. He prefers iron-wire cloth of $\frac{1}{8}$ -inch to $\frac{1}{4}$ -inch mesh, but finds that 10 to 30 wires per linear inch answer the requirements. The specifications show a deposition box containing an interior compartment filled with wire cloth, and provided with transverse partitions so arranged as to force the solution alternately down and up through the wire cloth. On either side of this interior compartment are two outer compartments separated from the inner one by diaphragms. Outside the diaphragms the vessel contains a 1 to 5 per cent solution of soda, and in this latter solution zinc-plate anodes are placed, forming with the cathodes a galvanic cell. This cell, when the anodes and the cathodes are connected, forms a circuit which, it is claimed, will rapidly cause the metal to be deposited on the wire cloth, and the zinc plates to dissolve in the soda solution. It is evident that in this apparatus no exterior electrical power is used. The electromotive force available is limited to 0.6 to 1 volt.

Julian and Smart^a give the capacity of a 1-ton box as 16 tons per 24 hours. The process seems to have been abandoned.

Oscar Froelich, U. S. Patent 556092, March 10, 1896.—Lead cathodes and carbon anodes are used. The current density is 6 amperes per square yard. The solution is seemingly clear.

Rudolf Keck, U. S. Patent 566986, September 1, 1896.—Clear solution, lead anodes, and aluminum cathodes.

Emile Andreoli, U. S. Patent 568724, October 6, 1896.—An apparatus for the electrical deposition of gold and silver in a tank provided with one or more anodes and a series of amalgamated cathodes. Each cathode consists of a pervious skeleton of knit-wire plates upon a layer of mercury in the bottom of the tank, into which the cathode dips. This patent discloses the use of peroxidized lead as anodes. The solution used is clear. Anodes are contained in compartments separated from the cathodes by permeable membranes. According to the description, only two anodes are used. The inventor places the anodes on the sides of the tank. The cathodes dip into a bath of mercury at the bottom. The use of the network of wire gauze is specified. The diaphragms are made preferably of porous asbestos or kieselguhr (infusorial earth) porcelain, but woven tissues stretched on frames may be used. It is specifically stated that the porous partitions may be omitted, and that the cathodes may be placed crosswise, one perforated anode being used for 12 to 15 cathodes. The patent shows a great advance in the art, particularly the use of peroxidized-lead anodes, which is a valuable discovery. The use of the wire cloth is also good, but the process necessitates the use of a large volume of quicksilver in the bath, which is a serious disadvantage, although it is convenient in making the electrical connections. However, the process does not appear to be practicable on account of the great difficulty of removing the gold and silver from the cathodes.

Andreoli^b has written an interesting article on the electrical deposition and recovery of gold. In this article he explains his discovery of the peroxidized-lead anode. He states that this anode was not the result of research or study, but was simply a chance discovery. His first plates were made according to the Plante method, but, at present, he prefers to use plumbate of soda repeatedly to coat the plates with peroxidized lead. When so treated the plates are drawn, washed, and placed in a strong solution of cyanide of potassium, where, under a heavy current, they become hard and acquire a crystalline appearance. In reference to his process Andreoli states: "I was soon disappointed when I was told that no one in mining districts would care much to adopt such a process which involved too much

^a Julian, H. F., and Smart, Edgar, Cyaniding gold and silver ores, 1904, p. 120.

^b Andreoli, E., Electrodeposition and recovery of gold: Jour. Soc. Chem. Ind., vol. 16, Feb. 27, 1897, pp. 96-97.

trouble in distilling the mercury and cleaning the plates in order to recover the gold amalgamated with it." He therefore altered the process by using cathodes of iron plates, upon which the gold and silver were deposited. He then recovered the gold and silver from the iron plates by dipping them in molten lead, whereupon the gold and silver alloyed with the lead and the plates were stripped. However, the iron plates are said to have become warped by the treatment with the hot lead, so that they easily produced short circuits. The only part of the Andreoli process that has been permanently adopted is the use of the peroxidized-lead anodes.

Max Netto, U. S. Patent 573233, December 15, 1896—This process consists in precipitating silver and gold from alkali-cyanide solutions by acidulating with hydrochloric acid so as to precipitate silver chloride, separating the precipitated silver chloride by filtration from the solution, and subjecting the acid filtrate to the action of an electric current so as to deposit the gold on the cathode. The inventor regenerates the cyanide solution by the addition of caustic alkali.

Precipitation of silver and gold in the presence of cyanide of potassium by hydrochloric acid is seldom complete. If the solution is high in cyanide and low in gold no precipitation of gold occurs; but if the solution contains a small amount of cyanide and a large amount of gold and silver, a certain amount of gold always comes down with the silver.^a On account of these reasons and the cost of the acid and alkali, it would seem that the process is hardly practicable, except where acid and alkali are much cheaper than cyanide.

J. F. Webb, U. S. Patent 585492, June 29, 1897—A method and apparatus for separating precious metals from their solvent solutions. The specifications show a box containing alternate vertical columns of zinc shavings and carbon. The carbon is said to be either charcoal or coke. The solution passes down through the charcoal and up through the zinc, the first compartment containing carbon and the last one zinc. The terminal columns of carbon and zinc are connected by wire, and electrical action between the carbon and the zinc is claimed. The inventor does not, however, rely upon this connection alone, claiming that the zinc and charcoal act sufficiently without the connection. As ordinary charcoal is not a conductor of electricity, there can be here electrical action only between the coke and the zinc, and the use of an external source of current for the process can not be claimed. Practically only local action can take place.

E. Andreoli, U. S. Patent 598193, February 1, 1898—An apparatus for the electrical deposition of gold, silver, and other precious

^a See Christy, S. B., Solution and precipitation of cyanide of gold: *Trans., Am. Inst. Mining, Eng.*, vol. 26, 1896, pp. 747-748.

metals. The inventor uses anodes of peroxidized lead acting in the presence of and in combination with the cyanide solution. The cathodes are made of perforated zinc plates.

The first great improvement over the Siemens & Halske process was the introduction of the peroxidized lead anodes discovered by Andreoli. When the lead plate was covered with a perfectly continuous film of peroxide of lead the anodes were practically unattacked by the cyanide solution, but whenever this film became broken, so as to expose the metallic lead, a white funguslike growth of hydrate and cyanide of lead formed upon the lead which was almost as destructive as the hydrate of iron that forms on the iron plate. When this action takes place, lead anodes are soon corroded and finally fall to pieces. Mercury also rots lead plates and soon destroys them. Experiments that I have made show that, in cyanide of potassium, the peroxide-of-lead anodes are practically unacted on when new, but that, in the presence of potassic hydrate, they dissolve slightly and a trace of lead comes down on the cathode.

The solubility of PbO_2 in KC_y and KHO was shown in experiments made November 26, 1900. I took as an anode an old peroxidized plate from a storage battery and as a solution 0.2 per cent potassium cyanide. As a cathode I used a platinum sheet $6\frac{1}{2}$ by 8 centimeters. The weight of the platinum cathode before treatment was 18.6734 grams. When treated with a voltage of 4 volts and a current of 0.068 to 0.11 ampere for two hours the cathode of platinum, which had previously been carefully cleaned, actually lost 2 mg. in weight. This result was typical of many experiments, and the results of other experimenters show similarly a slight loss of platinum from cathodes in cyanide electrolysis. Certainly at this time no lead was deposited. To the solution was then added KHO to bring the total to 0.1 per cent free KHO . For two hours the voltage was again 4, and the current 0.171 to 0.070 ampere. The gain in weight of the platinum cathode was 0.7 mg., caused probably by deposited lead. I then added salt to make 0.2 per cent NaCl and continued the treatment for 16 hours with a voltage of 3.7 to 3.42 volts, and a current at 0.2 to 0.56 ampere. The gain in weight of the cathode was 8.2 mg. The conclusion was that dilute solutions of KC_y do not alone attack peroxide of lead in two hours, but that KC_y containing KHO and NaCl do attack it slightly.

Kern* claims that peroxidized lead anodes fail, owing to the electrolyte attacking the lead through the pores in the peroxide coating, but I believe this to be more likely due to cracks in the brittle coating of peroxide caused by the easy bending of the lead within.

* Kern, E. F., *Electrolysis of cyanide solution*: *Trans. Am. Electrochem. Soc.*, vol. 24, 1913, pp. 241-270.

N. S. Keith, U. S. patent 597820, July 25, 1898—A process for treating ore with a cyanide solution containing cyanide of mercury. The gold and silver are recovered from the filtered solution by passing a current of electricity of less than 1 volt through suitable anodes and cathodes upon which the metal deposits as a coating of amalgam. I saw this process in operation in the year 1898. The ores came from Cripple Creek, Colo., and were treated at Cyanide, Colo. The anodes and cathodes were both of sheet iron, and the solution passed alternately up and down between the electrodes.

EXPERIMENTS WITH KEITH PROCESS AT CYANIDE, COLO.

I am indebted to Mr. Philip Argall for the following data on the use of the Keith process. From March 31 to April 9, 15 tons of solution was used to treat 83 tons of ore, the precipitated solution being used over again. The precipitation process is of chief interest.

The precipitation was conducted in a tank 12.5 by 3 by 4 feet, having a total content of 150 cubic feet, or containing about 5 tons of solution. It treated 7 to 13 tons a day, or an average of 10 tons. That is, a 1-ton tank would have had a capacity of about 2 tons in 24 hours. The anodes and cathodes were of sheet iron 4 by 3 feet. There were 50 cathodes so that the total area on both sides was 1,200 square feet. As there were 20 amperes flowing through the box, the current density was about 0.017 ampere per square foot. The potential varied from 0.5 to 0.9, averaging 0.75 volt.

From March 31 to April 9, the solution treated was used in leaching ore. During this time the solution entering the box ran from 1.605 to 0.215 ounces of gold, and that leaving the box ran from 0.385 to 0.107 ounce. On two days it left the box richer than it entered, but as no record is given of voltage and amperes for those days there may have been a defect in the current. The best precipitation was 76 per cent (the first day); the precipitation varied from that figure to 15 per cent and less, or even to negative value.

From April 10 to 21 the solution was no longer used to treat ore, but was pumped back to a tank and allowed to flow repeatedly through the box at the rate of 10 tons per day to indicate what the precipitation process could do. In 12 days gold content of the heads was reduced from 0.135 to 0.050 ounce. The solution was treated at the rate of 2 tons a day in a 1-ton box, or of 12 to 22 pounds per 24 hours per square foot of cathode surface. As the box was 12.5 feet long and there were 51 anodes and 50 cathodes, the average distance between the electrodes was 1.5 inches. The same solution when afterwards passed only once through boxes of zinc shavings was reduced to 0.015 ounce, or about 30 cents a ton. The original solution used by Prof. Keith contained 0.19 per cent KCy and 0.66 per cent NaHO,

and the final solution contained 0.04 per cent KCy and 0.155 per cent NaHO. There was used also 12 pounds of HgO. Mr. Argall comments as follows:

During deposition a black deposit collected on the cathodes, interfering with precipitation. This deposit had to be cleaned off three times. The material collected was chiefly of a graphitic nature, oxide of mercury and gold. The gold recovered from the black mud amounted to 25.7 per cent of the total gold recovered.

The mercury appeared to be the first metal deposited; consequently, the plates from the center to the end of vat were very hard, and the amalgam was extremely difficult to remove. When I decided to make a complete clean-up and abandon the process, some 5 pounds of mercury oxide was dissolved in the solution to soften the plates, and even with this addition of mercury it took two men one week to clean 50 plates, and when they had scoured off all the deposit possible, using mercury freely in rubbing the plates, there still remained on or in the plates 41.5 per cent of the total gold recovered.*

Recapitulation:

	Per cent.
Gold recovered as amalgam.....	32.8
Gold recovered as mud.....	25.7
Plates in 1 per cent cyanide solution.....	41.5

The cathodes were attacked and pitted somewhat. The anodes did not show much action, though a little Prussian blue appeared in places.

The result of this test led to the abandonment of the Keith process. Seemingly, the small amount of action on the anodes, which were nearly covered with a thin, hard scale of ferric oxide, was due to the low voltage used. This was always less than 1 volt. Curiously enough, the best precipitation was from a rich solution, on the first day, when the voltage recorded was only 0.5 volt. According to Mr. Argall the mercuric cyanide seemed slightly to hasten the solution of the gold, but not sufficiently to justify its use. This has been denied. Mr. Claude Vautin states that experiments in Hungary (1893-95) showed that the use of mercuric cyanide actually retarded the solution of the gold. I think that it probably retarded the precipitation of the gold.

In the light of further experience there were shown to be three serious defects in the process as conducted. First, the voltage was too low. The good results obtained upon the first day, with 0.5 volt, were doubtless due to the fact that the cathodes were of naked iron; but as soon as the cathodes became coated with gold, a back electromotive force operated to oppose further deposition of gold. The second defect was the use of mercury, the surface tension of which increased the difficulty of precipitation. The third defect was the sluggish circulation. The difficulties of the clean-up would largely disappear in regular work, just as they do in the use of amalgamated copper plates. It would be as difficult finally to clean them.

* This was subsequently recovered by soaking the plates in a 1 per cent KCy solution.—Author.

FIRST DEVELOPMENT OF THE CHRISTY PROCESS.

When I first looked into the electrodeposition of gold and silver from cyanide solutions it seemed to me that the low ampere-hour efficiency in the Siemens process was a fatal bar to the success of electrical deposition, and I was not surprised that the process was abandoned in South Africa shortly after Mr. Butters left there. But in discussing the matter with the late Stephen D. Field, the well known electrical engineer, my attention was called to the fact that the ordinary telephone has less than 1 per cent of electrical efficiency, and yet it is one of the most successful of modern inventions. This suggestion caused me to attack the problem with renewed interest, as I thought the method might still be made effective if given more careful study. Siemens was well aware of the importance of having a large electrode area, and he especially calls attention to the importance of increasing this rather than the voltage of the bath.

I soon came to the conclusion that all electrical processes that used quicksilver, either in the liquid form or in the form of amalgamated plates, except for treating free gold, coarse enough to overcome the surface tension of the mercury, were not likely to be successful with cyanide solutions. Such processes involve the use of a large amount of expensive metal, difficult to handle without loss, and involve the danger of salivation of the workmen. Moreover, there is the difficulty, already mentioned, arising from the necessity of overcoming the surface tension of the metal. This difficulty was particularly evident in the test of the Keith process at Cyanide, Colo. There was also great difficulty in recovering the amalgam from the large area of the cathode plates necessary for a complete precipitation. I noticed, moreover, that so long as the solution contained no sulphates or chlorides the anode plates, of iron, were little acted upon, being simply covered with a thin film of ferric oxide which protected the metal from further action, although it slightly increased the resistance.

Starting with the principle that an enormous cathode surface was necessary for the rapid and complete precipitation of the gold and silver, I made a number of experiments, using sheet iron for both cathodes and anodes. I found that when the current was not too great the precipitated gold and silver adhered firmly to the surface of the sheet-iron cathode. I then removed the cathodes, two at a time, and made them anodes in a dilute cyanide solution of about 0.1 per cent, and redissolved and reprecipitated the gold electrolytically upon a piece of sheet iron covered with a thin film of graphite and vaseline. On graphiting the surface of the sheet iron I found it possible, under proper conditions, to reprecipitate the gold and

silver in a dense coherent sheet, which afterwards could be stripped in sheets ready for the mint.

On February 6, 1900, I was granted U. S. patent 643096, for "a process of progressive electroconcentration and recovery of gold and silver contained in the large volumes of dilute cyanide solution containing free alkali resulting from the extraction of gold and silver ores, tailings, and concentrates, which consists first in depositing the gold and silver electrolytically from said solution upon removable cathodes sufficiently numerous and large in area to secure efficient deposition, and second, in making said removable original cathodes successively anodes in a smaller volume of cyanide solution, and transferring and depositing electrolytically the thin film of gold and silver already distributed over a large number of said original cathodes upon a smaller number of secondary cathodes, also contained in said smaller volume of cyanide solution."

EXPERIMENTS AT STANDARD CONSOLIDATED MINE, BODIE, CAL.

In the summer of 1900 I tried this process on a small scale at Bodie, Cal. The solution treated was 0.937 short ton, having an assay value of 0.175 ounce of gold and 0.437 ounce of silver. Although the metal values were almost entirely in the gold, there was nearly three times as much silver as gold in the solution. The assay value of the head solution was about \$4 per ton, gold and silver. The average of the entire solution after treatment was only about 10 cents a ton, some assays being as low as 2 cents. All the assays were made by the company assayer, W. M. Knox. Samples of eight assay tons of solution were assayed by evaporation with litharge.

The deposition box used was 2 feet 6 inches by 4 inches by 6 inches, and held 0.4 cubic foot. It treated solution at the rate of 2 cubic feet per day, or five times its capacity, with good results, but on pushing the work beyond the capacity of the box, the value of the tailing would run up to 20 or 30 cents.

There were 27 cathodes of thin sheet iron, 4 by 5 inches; hence their exposed surface on both sides was 7.5 square feet. The current varied from 0.5 to 1.3 amperes, the cathode current density varying between 0.066 and 0.173 ampere per square foot, averaging 0.135 ampere. For a part of the time, two boxes were used, in series, as far as solution was concerned, but electrically in parallel; hence the current density was then only 0.068 ampere. The voltage varied from 0.8 to 3.6 volts. The electrodes were all placed transversely across the box and $\frac{1}{2}$ inch apart, so that the solution flowed alternately up and down the box. Alternate anodes projected above the surface of the solution and were perforated with $\frac{1}{4}$ -inch holes to allow the solution to flow through. The flow through these holes

was more rapid than usual, and I found the deposit opposite these holes to be thicker and better than elsewhere. This discovery first suggested to me the advantage of rapid circulation through pervious electrodes, an idea that was developed later.

In order to preserve the anodes from corrosion they were coated with a mixture first suggested by Mr. Bettal of South Africa. This mixture consists of graphite, litharge, boiled oil, and turpentine; it is put on hot. I found that with a low current density (voltages up to 0.14 volt) the anode coating stood up well, as was claimed for it, but that as soon as the pressure was raised to 2 or 3 volts, in order to increase the precipitation, the boiled oil and turpentine were attacked, producing a vile-smelling mixture. The iron was then so attacked that the anodes had to be scraped clean.

There was considerable trouble in getting a continuous, direct-current service of a proper voltage. Alternating current was brought from a distance and was erratic, so that, although for a part of the time, direct dynamo service was available, frequent resort was necessary to a couple of large improvised Daniell cells.

THE CLEAN-UP.

The clean-up was effected in a cell that held 750 c. c. of cyanide solution, and accommodated two anodes (two cathodes from the deposition box, to be stripped) and one sheet-iron cathode, on which the gold and silver were to be precipitated. This cathode was coated with a layer of graphite and wax, put on hot, and rubbed dry with graphite, to favor the subsequent stripping of the concentrated metal. With two Daniell cells giving 1.4 volts in closed circuit, 0.200 ampere was obtained, but this fell rapidly to 0.050 ampere. The iron anodes did not appear to corrode, yet some of the metal came down rather loosely on the cathode which became coated evenly with silver and gold. The clean-up solution, which at first was 0.1 per cent KCy, was afterwards made 1 per cent. The cathodes from the head of the deposition box required about 1 hour for stripping, and those from the tail required only a few minutes. The cathodes from the deposition box (anodes in the clean-up box) showed no signs of pitting except in one instance when the current was left on over night. If the stripping was stopped when nearly complete the oxidation of the anodes in the clean-up box could be easily avoided, especially as clean cyanide solution free from chlorides and sulphates could be used for stripping. While the metal was partly adherent to the the cathode, much of it came down as a dark, blackish-brown powder, easy to filter and to melt. In later experiments the deposition of this precipitate was avoided by proper circulation. The scrapings from the anodes of the deposition box after treating

the mill solution contained graphite, linseed oil, etc., with more or less hydrate of iron and Prussian blue; weighed about 316 grams; and carried 0.16262 gram in gold and 0.30785 gram in silver. The total clean-up resulted as follows:

Clean-up in experiments at Bodie, Cal.

	Gold, grams.	Silver, grams.
From solid metal from cathode of clean-up box.....	1.61678	4.14322
From metallic dust from clean-up box.....	1.95100	5.53900
From cyanide solution from clean-up box.....	.44346	.85814
From wash water from anodes in clean-up box.....	.14936	.36704
From various sediments from deposition box.....	.16362	.30785
	4.32322	11.21525

The original solution treated was 0.937 ton, which assayed 0.164 troy ounce of gold and 0.435 troy ounce of silver; hence in grams the result was as follows:

	Gold, grams.	Silver, grams.
Original content	5.11	12.70
Actual recovery	4.32	11.22
Lost in tailing solution, assay samples, etc.....	.79	1.48

An 8-assay-ton charge of the tailing solution from the whole charge gave 0.005 ounce of gold per ton and 0.005 ounce of silver; that is, the tailings were worth a little more than 10 cents a ton, and there were left in the 0.937 ton of solution only 0.146 gram each of gold and silver. Hence the result was as follows:

	Gold, grams.	Silver, grams.
Original content.....	5.11	12.7
Residual solution.....	.146	.146
Difference	4.964	12.554
Actually recovered in clean-up.....	4.323	11.215
Losses and assay samples.....	.641	1.239
Loss in tailing.....	.146	.146
	* 7.87	^b 1.385

EFFICIENCY OF DEPOSITION.

The total time of the experiments during which the current was passing was 127.5 hours. The total number of ampere-hours was 126. The weight of gold actually recovered, divided by 7.35, the weight in grams of gold that should have been deposited in 1 ampere-hour, was as follows: $\frac{4.323}{7.35} = 0.588$ ampere-hour, which should have

* Compare with the 0.79 value given above.

^b Agrees with the 1.48 value given above.

sufficed to deposit the amount of gold at 100 per cent electrical efficiency. The weight of silver actually recovered, divided by 4.025, the weight in grams of silver that should have been deposited in 1 ampere-hour was: $\frac{11.215}{4.025} = 2.79$ ampere-hours, which should have sufficed to precipitate that amount of silver at 100 per cent electrical efficiency.

Therefore a total of 3.378 of the 126 ampere-hours was actually utilized. Hence the total electrical efficiency was: $\frac{3.378}{126}$, or 2.68 per cent. This is a much higher efficiency than that of the Siemens & Halske process, and the capacity, being at the rate of 5 tons per 24 hours in a 1-ton box, is nearly double. The reason for the higher efficiency is that a shorter current gap is used, being only $\frac{1}{4}$ inch, as against $1\frac{1}{2}$ to 3 inches. In the Siemens & Halske process it is not possible to bring the electrodes near one another on account of the danger of short circuits from the loosely hanging lead-foil cathodes. It is probable that in practice I should have had to increase the distance between the electrodes, owing to corrosion of the anodes; but with peroxidized-lead anodes, provided with vertical separators of wooden strips, placed about 6 inches apart horizontally, better precipitation could have been safely obtained with even a $\frac{1}{4}$ -inch current gap.

CRITICISMS OF THE CHRISTY PROCESS.

In 1903 there appeared in Halle a small volume on "Cyanide processes of gold recovery," being one of the "Monographs on applied electrochemistry," edited by Viktor Engelhardt, chief engineer and chief chemist of the Siemens & Halske Co., Vienna. This particular book is written by Manuel von Uslar, with the assistance of Dr. Georg Erlwein,^a engineers of the Siemens & Halske Co., Berlin.

From this combination of electrochemists, representative of Siemens & Halske, much might have been expected, particularly as regards a description of the Siemens & Halske process; but although the process is mentioned, the description is meager and the fund of information that might have been reasonably expected is entirely missing. Concerning my process of "progressive electroconcentration" these authors remark:

Attention need only be called to the great sums that must be invested on the large scale in the form of sheet gold and silver to show that this patent can scarcely lay claim to practical consideration. As regards technical considerations it must be remarked that there are insuperable difficulties in continu-

^a Von Uslar, Manuel, and Erlwein, Georg, *Cyanid-Prozesse zur Goldgewinnung: Monograph. angew. Electrochemie*, 1903, Halle, Germany, 100 pp.

ously watching the electric current, so that anodes to be stripped of their gold (cathodes from bath 1) shall remain in bath 2 exactly till their gold covering shall be removed, which for a rational operation is quite necessary, as otherwise probable losses of gold, of current, power, and electrode material are unavoidable.

I am ready to admit many defects in the process as it appeared in 1900; these I shall refer to later; but the defects that require consideration are not those mentioned by the distinguished authors. No gold and silver sheets have to be provided except those formed in the ordinary course of the clean-up.

Of the Siemens & Halske process, Von Uslar and Erlwein* speak as follows:

Every month with electrolytic precipitation likewise the clean-up takes place, which, however, is simpler than with the zinc precipitation. Without interrupting the operation one lifts the single cathodes out of the bath in which a newly charged frame (cathode) is replaced, an operation which requires only a few minutes.

They then go on to describe the drying of the lead sheets, and the fluxing and smelting of the lead cathodes weighing 12 to 20 times the weight of the contained gold and silver, all of which has to be cupelled to recover the 6 to 8 per cent of gold. Anyone who has had any experience with the Siemens & Halske clean-up is well aware of the great danger of loss in handling the cathodes during and after the drying. The monthly clean-up withholds from circulation the same amount of gold and silver as any other process that requires a monthly clean-up.

With the Christy process, the cathodes, when charged, may be removed for stripping and be replaced by a clean cathode without interruption, as in the Siemens & Halske process. Moreover, with the Christy process, a weekly or even a daily clean-up is possible, so that it is not necessary to keep so much gold and silver in an unproductive state; neither must 12 to 20 pounds of lead be cupelled for each pound of gold, nor must the lead be reduced and rolled into sheets to be again used as cathodes.

As regards the second criticism of these authors, namely, that of a necessity of watching the current to determine exactly when plates are stripped, the criticism is not warranted. If 1 volt or less is used in the clean-up box the plates strip rapidly, do not corrode appreciably, and require practically no attention except removal, washing, and replacing in the deposition box for a new coating. If necessary, an electric bell could be devised to indicate when the plates were sufficiently stripped. When the solution in the clean-up box becomes rich, by raising the voltage the gold and silver are recovered by electrolysis much more easily than from the original solution.

* Von Uslar, Manuel, and Erlwein, Georg, *Cyanid-Prozesse zur Goldgewinnung*: Monograph. angew. Electrochemie, 1903, Halle, Germany, 100 pp.

Since writing the above statement I have seen an important paper by Neumann.^a He remarks, "It is true Christy's proposition has some weak points, but certainly it does not fail for the reason given by Von Uslar and Erlwein." Neumann gives the results of some valuable experiments on the efficiency of electrical precipitation under the conditions of the Siemens & Halske process. However, he did not entirely reproduce the conditions, but kept the gold content constant by adding gold to the solution and, instead of keeping a constant voltage as in the Christy process, he maintained a constant current with increasing voltage. He seemingly did not attempt a complete precipitation as is necessary in practice. With a current density of 0.5 ampere per square meter, and with 10 grams of gold present per cubic meter, he found as a maximum efficiency 3.81 per cent; whereas, for the same density of current and with 3 grams of gold present per cubic meter, the efficiency is only 1.33 per cent. With a lower current density he got, for 0.25 ampere per square meter and 10 grams of gold per cubic meter, an efficiency of 7.56 per cent, and for 3 grams of gold per cubic meter, 3.15 per cent. For greater current densities such as 2.4, 4, and 9 amperes per square meter, and with 10 grams of gold present per cubic meter, he found the maximum efficiency to be 0.41, 0.24, and 0.16 per cent. It is evident that if the attempt had been made to reduce the gold content to a minimum the efficiency would have been lower.

Neumann points out what he claims to be the weak points of the Christy electroconcentration process. First, he claims that neither lead nor iron can be used alternately as cathodes and as anodes in cyanide solutions, as those metals are attacked by the cyanide and rendered unfit to serve as cathodes after having served as anodes in the clean-up cell. He fails to observe that the Christy patent states, "The anodes and cathodes may be made of any electroconducting material not too strongly acted on by the solution." Though lead and iron are mentioned, the Christy patent is not confined to their use. I have successfully used Acheson graphite sheets and other forms of carbon. I am ready to acknowledge that there is difficulty in the use of lead. However, the difficulty does not arise from the cause assigned by Neumann, but from local action if the electrodes are not used continuously and are put away damp.

Neumann quotes some experiments, made presumably under his direction, by Mr. John Johnston, in which gold was deposited on carbon cathodes after which an electric clean-up was attempted, supposedly with the Christy process. In the first four experiments,

^a Neumann, B., *Electrolytic precipitation of gold from cyanide solutions*: *Electrochem. and Met. Ind.*, vol. 4, August, 1906, p. 300.

with a current density of 992 to 118 amperes per square meter, no gold at all was deposited. (Seemingly, the current deposited the gold in the form of slime, which was easily washed off by the violent agitation.) With 24 to 69 amperes per square meter the efficiency, 0.03 to 0.045 per cent, was low, and was higher with the lower density. The voltage, an important item, is not given. The stripping went on easily, but he forgets that the cyanide solution was strong—17.76 to 12.1 per cent. It is remarkable that any gold was precipitated from so strong a solution of free cyanide.

Examination has been made of samples of the silver and gold precipitated by the Christy process, the metal having been first deposited upon iron cathodes from weak solutions, then redissolved by making anodes of these cathodes in a 0.1 to 1 per cent cyanide solution, and reprecipitated upon sheet-iron cathodes, coated with a film of graphite and vaseline. The samples showed that it is possible to deposit coherent sheets of both gold and silver by the Christy process in exactly the way specified in the patent. After wrongly condemning the process as impossible, Neumann proposes to resort to carbon cathodes, which he would strip, causing the gold to be redeposited by the Wohlwill process, sodium chloride, gold chloride, and free hydrochloric acid being used as an electrolyte. By this means good results are obtained with pure gold, and a high efficiency results; however, upon calculating the gold as univalent the efficiency would be modified.

Mention should be made of the fact that the Wohlwill process is not applicable to alloys containing more than 10 per cent silver. With solutions carrying, as many do, more silver and copper than gold it is doubtful whether this ingenious modification of the Christy method would be applicable. The process could not be used to produce fine gold, as Neumann supposes, but by using cyanide, of a proper strength, and employing a proper voltage, the gold and silver could be recovered if the process were properly conducted. The operation is especially easy if cathodes composed of thin sheets of Acheson graphite are used as "cathode anodes." As pure cyanides free from sulphates and chlorides can be used in the stripping box, they are little corroded at the low voltage used in the Christy process.

SUBSEQUENT PATENTED PROCESSES.

C. P. Stewart, U. S. patent 676526, July 16, 1901.—The solution flows over a stationary mercury cathode. The process is similar to the "Molloy process."

William Orr, U. S. patent 689018, December 17, 1901.—Inventor uses zinc anodes in cyanide solutions, especially when the solutions contain copper, and regenerates the cyanide by throwing down the zinc by KHO and Na₂S. The patent resembles one granted to C. H. Merrill for regenerating cyanide from solutions containing zinc.

E. D. Kendall, U. S. patent 698292, April 22, 1902.—The specifications of this process show an electrodeposition box containing carbon anodes in porous cells. The remaining space of the outer vessel is filled with fragments of carbon, which act as cathodes upon which the gold and silver are deposited. After sufficient time the caustic potash is withdrawn from the porous cell and a cyanide solution, adequately strong, supplied to fill it. The carbon plate is then removed and a silver-plated copper plate is made the cathode in place of the anode. The gold and silver dissolve from the first carbon anode and deposit upon the inner plate. The invention contains ideas shown in the Christy patent (No. 643096) previously mentioned, but without the removable cathodes. In one place the inventor specifies a pressure of 5 volts and in another preferably 15 volts. It is evident that the porous cell is a disadvantage, as it increases the resistance enormously. I can not find any place where the process has been applied.

S. Muffy, U. S. patents 714598, 714599, November 25, 1902.—This patent is for a process and an apparatus. A carbon anode is used with a cathode composed of a filiform mass of lead and zinc.

THE BUTTERS PROCESS.

Charles Butters (U. S. patent 756211, Apr. 5, 1904) claims the use of a dense current in combination with peroxide-of-lead anodes and tin-coated steel cathodes. His claims are as follows:

First. The improvement in the process of precipitating metals from solutions, chiefly cyanide solutions, which consists in employing cathodes having surfaces of tin and a high-density electric current, substantially as described.

Second. The improvement in the process of precipitating metals from solutions which consists in employing cathodes having surfaces of tin in combination with anodes of lead peroxide and a high-density electric current, substantially as described.

Third. The improvement in the process of the electrolytic separation of metals from solutions which consists in using a cathode having smooth surfaces of tin, substantially as described.

In the specifications, Butters directs that the anodes and cathodes shall be placed about 3 inches apart, and that the solution containing the metal or metals to be deposited shall be caused to flow between the electrodes, preferably in an upward or downward direction, at a uniform velocity, while an electric current of high density enters the cathode. In practice about 0.5 ampere per square foot of cathode is found suitable, as a rule. The dissolved metals are then deposited in a loose slimy form on the tin cathode surface and may be removed by brushing or wiping the plates with a soft material, such as rubber or wood. This may be conveniently done by removing the cathodes from the solution when the deposit is sufficiently thick, or usually by

running a wiper over the plates at intervals of, say, once a day while in position in the solution, and allowing the removed slime to settle to the bottom of the vessel. This slimy deposit is removed from the vessel at regular periods, and the metals are separated and refined in the usual way.

It may be noted that in the Christy patent, issued in 1900, I disclose the use of a dense current with flat electrodes in the following words: "The current should be so graduated that it (the gold) is deposited in a firm, coherent coat. If a strong current is used, the gold is deposited on a cathode as a fine brown powder, which may be brushed off at intervals and melted down; but I prefer to deposit it as a firm, coherent coat to avoid mechanical loss in handling." Butters's process has been developed on a large scale in several of his plants in this country, Mexico, and Central America, and may be said to be technically successful, but there are at least two practical objections to it. The first is that so high a current density as he employs to separate the material in a loose form on flat electrodes is wasteful. The second is that the recovery of the precipitated slime by removing the plates and wiping them by hand involves much labor, and if the precipitate is scraped from plates and allowed to accumulate at the bottom of the tank there is not only a danger of loss, either by resolution or by mechanical means, but the precipitate is liable to be contaminated by the peroxide of lead that occasionally drops from the anodes to the bottom of the tank, or especially by the precipitated carbonate of lime which is continually settling out of the solution.

That this contamination of the gold is serious I have demonstrated by analyzing a precipitate coming from one of the Mexican plants where the process was used. The precipitate from the head of the boxes contained enough lead and oxide of lead to make it melt almost like butter, but the precipitate from the lower end of the tank contained so much carbonate of calcium that fusing was difficult. The bullion produced from each precipitate was necessarily of low grade. Nevertheless the process is in successful use. It is probably the only electrolytic process now in actual use for the treatment of cyanide solutions from gold and silver recovery.

EFFICIENCY OF BUTTERS PROCESS.

An admirable account of the Butters process is given by Hamilton.^a The solution from the sand treatment has the following gold and silver content:

^a Hamilton, E. M., A development in electrolytic precipitation of gold and silver from cyanide solutions: *Electrochem. Ind.*, vol. 2, April, 1904, p. 131.

	Gold, pennyweights.	Silver, ounces.
Head solution.....	2.93	3.51
Tail solution.....	0.26	0.29
Precipitated per ton solution.....	2.67	3.22

There were precipitated, at 3 volts, 216 tons of solution a day; hence there was recovered 898.56 grams of gold and 21,632.40 grams of silver. In depositing the gold there was utilized $\frac{898.56}{7.35} = 122.2$ ampere-hours. In depositing the silver there was utilized $\frac{21,632.40}{4.025} = 5,374.5$ ampere-hours, making a total of 5,496.7 ampere-hours. The area of cathodes was 6,950 square feet, with a current density of 0.55 ampere per square foot, or a total of 3,822.5 amperes; and in 24 hours we have 91,740 ampere-hours, or an electrical efficiency of $\frac{5,496.8}{91,740}$, which is slightly less than 6 per cent ampere efficiency. There was precipitated 91.1 per cent of gold, and 91.7 per cent of silver.

The solutions from slime treatment had the following content:

	Gold, pennyweights.	Silver, ounces.
Head solution	1.10	1.45
Tail solution.....	0.13	0.15
Precipitated per ton of solution.....	.97	1.30
	1.5085	40.4345

There was precipitated, at 2.6 volts, 480 tons of solution per 24 hours, and the recovery was 724.08 grams of gold and 19,408.56 grams of silver. Hence there were utilized in precipitating gold $\frac{724.08}{7.35} = 98.5$ ampere-hours, and in depositing silver $\frac{19,408.56}{4.025} = 4,822$ ampere-hours, making a total in useful work of 4,920.5 ampere-hours. The cathode area (like that of the anodes) was 13,536 square feet. The density of 0.3 ampere per square foot gives a total current of 4,060.8 amperes; or, of 97,459 ampere-hours, only 4,920.5 were utilized, and the electrical efficiency was only 5.05 per cent. The results are much better than those of Siemens & Halske, owing to the use of peroxide of lead instead of rusty iron for the anodes and of bright tin instead of lead for the cathodes. There was precipitated 88.2 per cent of gold and 89.6 per cent of silver. It should be remarked that there was precipitated simultaneously by the current an amount of copper of almost half the weight of the silver. This would considerably increase the electrical efficiency.

* 4.16 grams.

* 100.15 grams.

Taking the results quoted in Hamilton's figures for November and December, 1901, and for convenience converting ounces to grams by multiplying by 31.1, the figures are:

	Grams.
Total gold deposited in two months.....	84, 872
Total silver deposited in two months.....	2, 204, 772
Total copper deposited in two months.....	1, 024, 030
For gold, dividing by 7.35, the number of ampere-hours utilized is.....	11, 547
For silver, dividing by 4.025, the number of ampere-hours utilized is.....	547, 769
For copper, dividing by 2.372, the number of ampere-hours utilized is.....	431, 716
Total (supposing copper to be univalent) number of ampere-hours utilized is.....	991, 032

During this time there was actually used 11,013,640 ampere-hours; hence the efficiency was 9 per cent. If, however, as Hamilton assumes, the copper was bivalent 432,000 ampere hours should be added for the copper, making a total of 1,423,032, or an efficiency of 12.9 per cent. Either result is a great improvement on that by the Siemens & Halske process.

In different experiments with various tonnages of these solutions, Hamilton has obtained efficiencies of 4.83, 6.10, 13.24 and 13.90 per cent, but he has not calculated the average. He has used practically the equivalents that I have taken for gold and silver, but for copper a decidedly lower one, being 1.206, as against the 2.372 which I used for univalent copper.*

It is altogether probable that copper, like gold and silver, is univalent in cyanide solutions; moreover, cupric cyanide is a very unstable compound. Gmelin and Hittorf both claim that copper dissolves only as cuprous cyanide. I have not investigated the subject, but have reason to believe that, at the anode, copper cyanides are formed which are of higher valence than 1, and that these compounds are subsequently reduced to others of lower valence at the cathode. This is one of the reasons that copper cyanide is so hard to precipitate by electrolysis.

STUDY OF CONDITIONS GOVERNING ELECTROLYTIC DEPOSITION.

It must be evident that the results obtained at Bodie were good, so far as precipitation is concerned. However, in 24 hours, with the box used not more than 5 cubic feet of solution could be treated per cubic foot of box capacity. The maximum duty of the deposition box would be at the rate of 5 tons a day for a box holding 1 ton of

* Standard Handbook for Electrical Engineers, 1915, pp. 1560-1564.

solution. This rate did not seem to me to be satisfactory, yet when I attempted to increase the velocity of the solution above this rate, a poor precipitation resulted.

While I was making these experiments at Bodie, it occurred to me that a good way to increase the capacity of the box would be to circulate the solution by pumping it repeatedly through the box, thus concentrating the gold and silver upon a smaller number of electrodes than would be necessary if the box were made large for complete precipitation by one passage. I then determined to make a systematic study of all elements necessary to procure complete and rapid precipitation of gold and silver by electrolysis. I had long investigated the effect of the current with sheet-iron electrodes upon a solution of cyanide of potassium at rest.

In referring to this past work I found that there had been used about one-half liter of 1 per cent cyanide solution at rest. Into this solution I immersed a sheet-iron anode $12\frac{1}{2}$ by 13 centimeters in size, and a sheet-lead cathode of about the same dimensions, spacing these $1\frac{1}{2}$ inches apart. I used a storage battery of approximately 2 volts at first, and after $2\frac{1}{2}$ hours raised the voltage to 4 volts. The resulting ampere curves and the cyanide curves are shown in figure 1.

The experiment lasted 45 hours. At the end of the period the cyanide was reduced to 0.03 per cent, showing that 97 per cent had been destroyed. It will be seen that the current diminished almost immediately, owing to polarization effects and oxidation of the

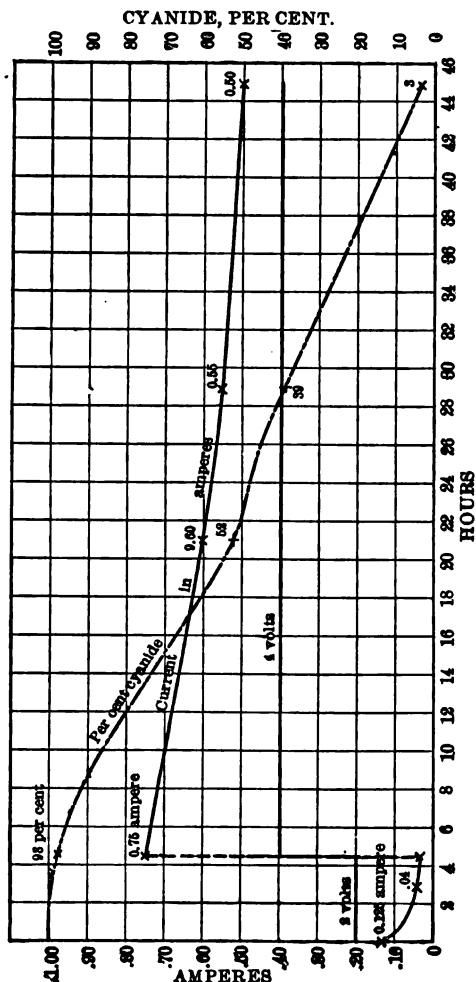


FIGURE 1.—Ampere-cyanide curves from experiments on effect of electrolysis on solution of cyanide potassium at rest. Volume of solution, 500 c. c.; KCy, 1 per cent; iron anode, $12\frac{1}{2}$ by 13 cm.; lead cathode, $12\frac{1}{2}$ by 13 cm.; separation, $1\frac{1}{2}$ cm.

anode. The anode was only slightly oxidized, an almost imperceptible film of oxide of iron having formed.

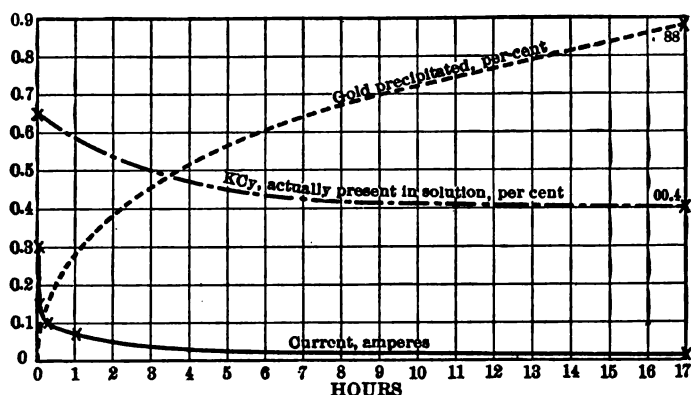


FIGURE 2.—Curves from experiments on electrodeposition of gold from solution of cyanide of potassium. Iron anode, $12\frac{1}{2}$ by 13 cm.; lead cathode, $12\frac{1}{2}$ by 13 cm.; current, 2 volts from storage cell; KCy, 0.065 per cent; Au, 0.005 per cent; volume of solution, 500 c. c.; Au, 2.5 mg.—\$3 a ton; electrodes $1\frac{1}{2}$ cm. apart.

Following these tests and in the same apparatus a cyanide solution was treated containing 0.065 per cent of free cyanide and \$3 a

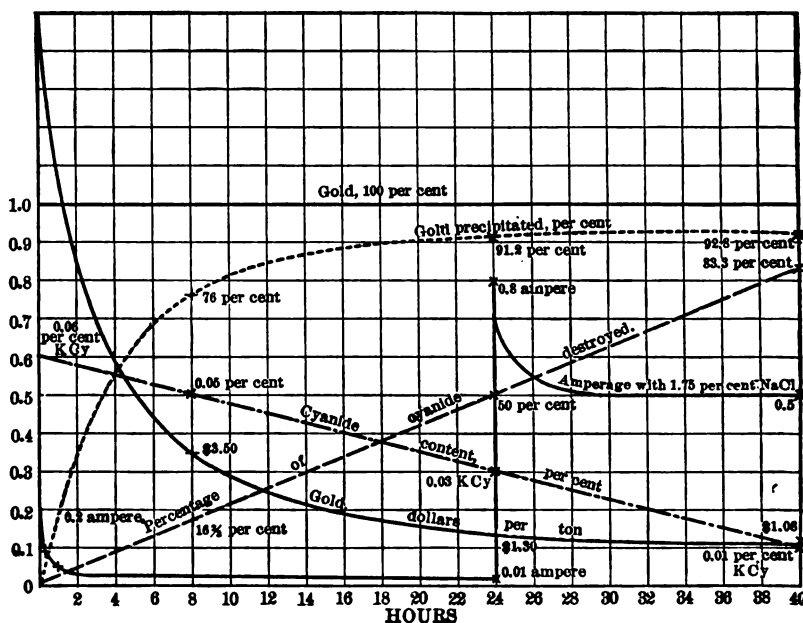


FIGURE 3.—Curves from experiments on electrodeposition of gold from solution of cyanide of potassium. Iron anode, $12\frac{1}{2}$ by 13 cm.; lead cathode, $12\frac{1}{2}$ by 13 cm.; electrodes $1\frac{1}{2}$ cm. apart; current, 2 volts from storage cell; volume of solution, 500 c. c.; Au, \$15 a ton; KCy, 0.065 per cent.

ton in gold. The results of the experiment showed that in 17 hours only 88 per cent of the gold was precipitated. The cyanide was con-

tinuously destroyed, only 0.04 per cent remaining at the end of the experiment. The results of this test are shown in figure 2.

In the same apparatus a 0.06 per cent cyanide solution containing \$15 a ton in gold was treated. One storage cell was used and the experiment lasted for 40 hours. The results are shown in figure 3.

At the end of 24 hours the gold was reduced from \$15 to \$1.30 a ton. One-half the cyanide then had been destroyed. At this time I added sodium chloride, a suggestion of Mr. Butters, so as to make a solution containing 1.75 per cent NaCl. The current jumped immediately from about 1 milliampere to 800, and at the end of 40 hours remained 100 milliamperes. The gold had been

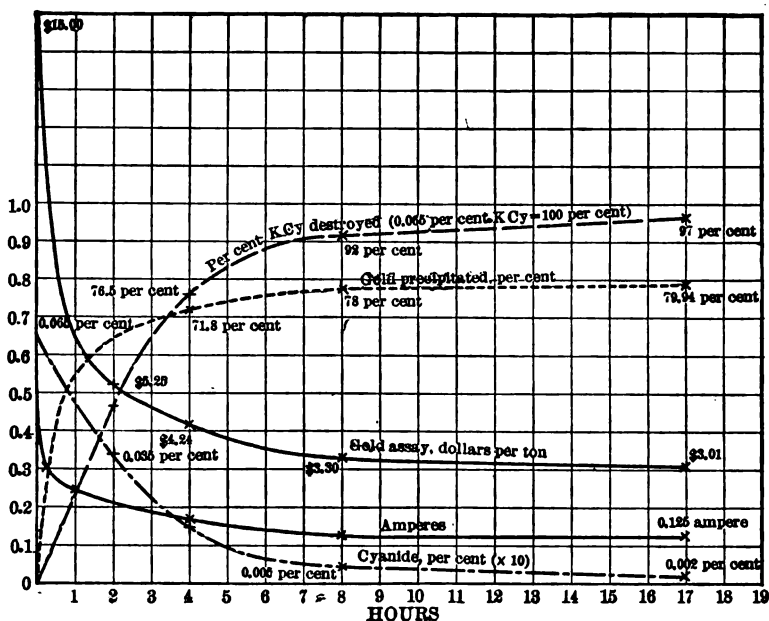


FIGURE 4.—Curves from experiments on electrodeposition of gold from solution of cyanide of potassium. Iron anode, $12\frac{1}{2}$ by 13 cm.; lead cathode, $12\frac{1}{2}$ by 13 cm.; electrodes $1\frac{1}{2}$ cm. apart; current, 4 volts from two storage cells; Au, \$15 per ton; KCy, 0.065 per cent.

reduced to \$1.08 a ton, and the cyanide to 0.01 per cent, so that only 83.3 per cent of the gold was precipitated. Five-sixths of the cyanide had been destroyed. The low rate of precipitation in this experiment led me to increase the voltage to 4 volts, using two storage battery cells. For this I used an 0.065 per cent cyanide solution containing gold to the value of \$15 a ton, the remaining conditions being as before. The results are shown in figure 4. At the end of 17 hours the cyanide had been reduced to 0.002 per cent, 79.94 per cent of the gold had been precipitated, and 97 per cent of the cyanide had been destroyed. The results did not then look promis-

ing, but when compared with the results of my later experiments, they show the great progress that has been made in this investigation.

One of the first things to be noted in the results is the rapid fall of the current, which continued to decrease throughout the whole process. I noticed that whenever either of the electrodes was agitated so as to displace the solution in immediate contact, the current immediately increased, falling again as soon as the solution came to rest and the conditions were reestablished by electrolysis. This was evidently due to the well-known phenomena of polarization. It was made evident by these experiments that the precipitation of gold and silver from cyanide solutions was a problem of great difficulties.

HOW DOUBLE CYANIDES REACT IN ELECTROLYSIS.

The solutions of the double cyanides seemingly act much differently from those, for instance, of either sulphates or chlorides of a metal like copper. With solutions of these latter salts rapid and complete precipitation would at once ensue. To those familiar with the conditions of electroplating gold and silver in cyanide solutions, the electrodeposition process seems to be a natural and easy one; but the conditions there maintained are different from those prevailing in solutions used in ore treatment. With solutions such as are used in electroplating the density is sufficient to produce a very good conductor. The solution is rich in gold or silver, and the metal deposited is replaced as fast as it is precipitated by a supply from the soluble anodes. Hence the electrochemical conditions are suitably maintained. However, in the treatment of solutions resulting from ore treatment, solutions have to be handled that assay less than \$6 per ton, and contain less than 0.001 per cent of metallic gold. This solution must, perhaps, be reduced to less than 6 cents per ton, or 0.00001 per cent of gold. No one would attempt such a task with a metal less valuable than gold or silver.

The first part of the gold in electrolysis is readily removed, but the deposition becomes increasingly difficult toward the end, and it is theoretically and practically impossible to remove the last traces of the gold from such solutions. The chief cause of the great difficulty is that the gold and silver form what are known as "complex ions" in the cyanide solution. For instance, if a solution containing pure KAuCy_2 but no free cyanide be considered, one is dealing with a substance which crystallizes in white crystals, looking very much like granulated sugar, soluble in water and forming a colorless solution. This solution, if sufficiently dilute, according to the ionic theory breaks up into two ions, the simple ion K carrying a positive charge of electricity, and the complex ion AuCy_2 carrying a negative

charge. When an electric current is passed through such a solution, with platinum electrodes, the potassium ion carrying the plus charge of electricity travels to the negative pole, and if there is sufficient gold cyanide in the vicinity it decomposes some of the cyanide, precipitating the gold on the cathode and setting free the cyanide. Meantime the complex ion AuCy_2 , with its negative charge of electricity, travels to the anode, and there forms a pale yellowish, slimy film which protects the anode from further action by the current. Hence, with such a solution, electrolysis soon comes to a stop, the anode being insulated by the slimy coat of AuCy_2 .^a As was proved by Hittorf,^b the same action takes place with potassium argentocyanide, the only outward difference being that the slimy film of AgCy_2 is white.

Because of the formation of the insoluble and insulating slimes on the anode it is always necessary, in electroplating, to have some free cyanide of potassium in the solution to redissolve this film. Caustic potash may be used instead, but is not so satisfactory. For instance, AuCy_2 partly decomposes into AuCy and Cy . The Cy partly oxidizes to cyanate and partly changes to cyanide of potassium. AuCy redissolves in the excess of free cyanide if present, or in KHO if only the latter is present. With the KHO , cyanate and cyanide of potassium are formed and the essential salt of the solution is regenerated. This rather complicated process is hard to understand and a little difficult to explain, but there is no doubt about its occurrence. As regards silver cyanide the reactions mentioned were demonstrated quantitatively by Hittorf.

In order to appreciate the importance of this peculiarity of cyanide solutions, consideration might be given to the electrolysis of nitrate of silver. The Ag goes directly to the cathode, and NO_3 travels to the anode. Hence for every atom of silver precipitated at the cathode one atom disappears from the solution near the cathode. But in the electrolysis of cyanide of gold or silver, for every atom of gold or silver precipitated at the cathode two atoms are removed by the current, one being precipitated by the K ion and the other traveling to the anode. Hence it must be evident that the action of the current renders further precipitation of the gold more and more difficult. Julian and Smart^c claim that this discovery was made by Daniell and Miller. They say—

Daniell and Miller (*Philos. Trans.*, 1844, p. 1) investigated the nature of the ions, and found that when an electric current is passed through a solution of KAuCy , or KAgCy , the K is the positive ion and goes to the cathode, while

^a See Christy, S. B., On the solution and precipitation of cyanide of gold: *Trans. Am. Inst. Min. Eng.*, vol. 26, 1896, p. 758.

^b Hittorf, W., Über die Wanderungen der Ionen während der Elektrolyse, 1859; reprinted in *Ostwald's Klassiker der exakten Wissenschaften* No. 23, 1891, p. 74.

^c Julian, H. F., and Smart, Edgar, Cyaniding gold and silver ores, 1904, p. 121.

the negative ion consists of gold or silver and cyanogen, and this goes to the anode. Hittorf has since confirmed this and assumes the negative ion to be AuCy_2 for gold and AgCy_2 for silver. That is to say, that when these complex salts are electrolyzed, the gold and silver move in the opposite direction to that taken in the case of simple salts.

The foregoing abstract quotation appears to contain several mis-statements: In the first place, nowhere in the reference given do Daniell and Miller make any reference to the cyanides of gold or silver. They do discuss potassium ferro and ferri cyanide, cyanide of potassium, and sulphocyanide of potassium, but nowhere in the article mentioned nor in any other of the Philosophical Transactions from 1842 up to 1860, do they make any statement that can be twisted into such an assertion. They state that they intend to investigate other cyanides, but they do not seem to have done so.

It may further be remarked that the work of Hittorf seems to have been both underrated and overrated. No references by Julian and Smart are given to Hittorf's^a work, a full account of which has been reprinted by Ostwald. The work of Daniell and Miller was of great importance to electrolytic science, but it contained numerous errors which were cleared up by the skillful work of Hittorf which is a model of scientific accuracy. Hittorf with punctilious care seems to have given full credit to Daniell and Miller for the good work done by them, but there is no mention of their having done any work with the cyanides of gold and silver. He seems to have been the first to have shown that in the electrolysis of a KAgCy_2 solution the K goes to the cathode and the AgCy_2 to the anode. However, he makes no mention of KAuCy_2 solution, though he does treat of HAuCl_4 .

Ostwald^b has collected data on all the known velocities of ionic transfer, and he gives the values for K and Ag (CN)₂, and credits the work to Hittorf. Nowhere is any mention made of K and AuCy_2 , though the list covers eight pages. Hence I assume that Julian and Smart have claimed too much for Daniell and Miller. Whether I was the first to call attention to the nature of the electrolytic reaction in solutions of KAuCy_2 ,^c I do not know; but I believe that I can fairly claim to have been the first to bring out the practical importance of it in electrodeposition from cyanide solutions. The reaction is of controlling importance in all electrocyanide processes and yet it is not understood by many of the writers on the cyanide process or by many authors of chemical textbooks.

^a Hittorf, W., *Über die Wanderungen der Ionen während der Elektrolyse*, 1859; reprinted in Ostwald's *Klassiker der exakten Wissenschaften* Nos. 21 and 23, 1891, 87 and 142 pp.

^b Ostwald, Wilhelm, *Chemische Energie*, 2d ed., 1893, p. 608.

^c See Christy, S. B., *The solution and precipitation of cyanide of gold*: *Trans. Am. Inst. Min. Eng.*, vol. 20, 1896, pp. 758-759.

Sir Humphrey Davy's original idea as to the composition of salts as against the ideas of his time has been confirmed by more recent scientific investigations. Daniell and Miller do not seem even to have been the first to discover the complex ions of potassium ferrocyanide, ferri-cyanide, and sulpho-cyanide. To Hittorf belongs the credit of expanding and completing the application of the results of early investigators to potassium silver cyanide. Ostwald deserves the credit of generally clearing up the subject by the invention of the term "complex ion." As far as I am aware he did not extend his work to include KAuCy_2 .

The separate experiments upon which I based the statements made in 1896 were with cyanides of silver, of gold, and of copper. I used pure solutions of the double salts of potassium and of the several metals without free cyanide. A platinum dish was the cathode, a platinum wire the anode. I found that the current was soon stopped by the formation of a nonconducting slimy coating of varied color. With KAgCy_2 the coating was of a pale white appearance and had a faint yellow cast. The slime from the KAuCy_2 was yellow with a pale green cast. With copper the anode slime was a bright grass green or yellowish green. The accumulation of any one of these precipitates gradually stopped the electric current. When the crust of precipitate was scraped off the anode, so as to fall on the cathode, it retained its shape but was reduced to the metal—silver, gold, or copper—according with the composition of the double cyanide. Similar crusts form on the anodes in electroplating when insufficient free cyanide is used, as is well known to all electroplaters, but I have not been able to find the explanation of this phenomenon in any of the many books on electroplating published before 1896.

Fortunately a comprehensive bibliography on this subject has been prepared by McBain.^a It is claimed to be complete to the end of the year 1905. All the work of Daniell is included in this outline, and no mention is made of his ever having determined the migration velocities of KAgCy_2 or of KAuCy_2 . The relative velocity of the potassium ion in KAgCy_2 was determined to be 0.594 in a solution containing 1 gram-molecule in $1\frac{1}{2}$ liters.^b Nobody seems to have determined the migration velocities of the ions of KAuCy_2 up to the end of 1905.

Unfortunately at variance with the statements made by Julian and Smart, the fact appears that Daniell was not the first to observe the true nature of electrolysis of complex ions.

^a McBain, J. W., Experimental data of the quantitative measurements of electrolytic migrations: Wash. Acad. Sci., vol. 9, July 31, 1907, pp. 1-78.

^b Hittorf, W., Über die Wanderungen der Ionen während der Electrolyse, 1859; reprinted in Ostwald's *Klassiker der exakten Wissenschaften* No. 23, 1891, 142 pp.

The first observer seems to have been Robert Porrett in 1814.^a The paper mentioned is signed "Tower, June 6, 1814." It would appear from the large number of French chemical terms used that Mr. Porrett must have been a Frenchman, probably residing in England, and not a member of the Royal Society.

Porrett seems to have had a correct idea of the composition of the salts known as triple prussiates, and to have fought the idea then prevailing that the triple prussiates were simple, double cyanides. Thus, he says:

I consider the salts termed triple prussiates as binary compounds of an acid with a single base; as salts which do not contain any prussic acid, nor any oxide of iron as a base, although both the substances may be obtained from them by a decomposition of their acid.

The first experiment which I shall adduce in support of the above opinion is one with the voltaic battery; it appeared to me that this instrument would show whether the oxide of iron in the triple prussiates existed in them as a base, or as an element of a peculiar acid by attracting it to the negative pole in the former, and to the positive pole in the latter case. I therefore exposed a solution of triple prussiate of soda to the agency of a small battery of 50 pairs of double plates of one inch and a quarter square, kept in action for 20 hours, the solution was connected by platinum wire with the negative pole, and by filaments of cotton with distilled water which communicated by platinum wire with the positive pole. Thus circumstanced the triple prussiate of soda was decomposed, its acid (consisting of the elements of prussic acid and black oxide of iron) was carried over to the positive pole; here meeting with oxygen from the decomposing water, it underwent a farther change by which it was converted into prussic acid which was partly volatilized, and into blue triple prussiate of iron which formed there in abundance; the liquid at the negative pole after this process contained only soda with a trace of undecomposed triple prussiate. In this experiment I consider the circumstance of the black oxide of iron being carried over to the positive pole as a proof that it went there as an element of an acid, for as a base it must have remained at the negative pole.

Porrett seems to have discovered also sulpho cyanate of potassium (which he calls "red-tinging acid") by boiling Prussian blue with sulphide of potassium, and also by heating to redness animal charcoal and sulphide of potassium, as well as by other means. He subjected this solution to the action of electrolysis and found that the new acid was carried to the positive pole without decomposition or the separation of any sulphur. This would clearly prove, it seems to me, that to Porrett belongs the credit of first proving the reaction that takes place when "complex ions," as they are now termed, are electrolyzed.

The first quantitative work on "transfer values" seems to have been done with sulphate of sodium by Faraday^b in 1833. Daniell's

^a Porrett, Robert, jr., On the nature of the salts termed triple prussiates, and on acids formed by the union of certain bodies with the elements of the prussic acid: *Phil. Trans. Roy. Soc. Lond.*, 1814, pp. 527-556.

^b Faraday, Michael, Experimental researches in electricity: *Phil. Trans. Roy. Soc. Lond.*, 1833, pt. 1, p. 36.

first work was reported in 1839, and his last work seems to have been done in 1844, whereas Hittorf's work was from 1853 to 1859.

The theories foreshadowed by Sir Humphrey Davy, proved to be true by Porrett and by Faraday, afterwards confirmed by Daniell and Miller, and carried to perfection in Hittorf's classic work, have been of the greatest importance not only to chemical science but to practical technology. The work of these men, not even yet fully appreciated, was for many years a subject of bitter controversy.

PRACTICAL APPLICATION OF THE LAW.

It soon became evident to me that the necessary electrolytic reaction with the double cyanides was one of the chief causes of slow precipitation, in short, that the gold content at the cathode was so rapidly diminished that the potassium ion when brought to the cathode by the electric current found there no gold to precipitate. Consequently, electrical energy was wasted, water being decomposed, and caustic potash and hydrogen were formed to no useful purpose. The gold was accumulated at the anode where it acted injuriously by increasing the resistance.

It occurred to me that both these evils could be at once met by a rapid circulation of the solution from anode to cathode, so that the gold collected at the anode, where it was doing only harm, could be swept to the cathode where the potassium ions, instead of decomposing water, would precipitate gold. With sheet electrodes it was not easy to obtain this result, whether, as in my first process, the electrodes were transverse to the box, and the circulation up and down between them, or whether, as in most recent installations of the Siemens and the Butters processes, the electrodes hung longitudinally in the box, and the solution passed directly between them. With none of these arrangements could the direct replenishment of the cathode solution, so necessary to good results, be effected. This requirement could be met only by the use of pervious anodes and cathodes, either of sheet metal or of wire cloth. Perforated sheet electrodes were first used but the cyanide of gold and silver accumulated on the anode spaces, between the holes, where the circulation was poor. I then resorted to the use of iron-wire cloth.

The first anodes were made of iron-wire cloth of 8 meshes to the linear inch, the wires being 1 mm. thick. A single sheet was used which was $3\frac{1}{4}$ inches wide by 4 inches high, only about $2\frac{1}{2}$ inches being submerged. It was stiffened by a thin, sheet-iron fold having a copper conductor riveted to the top. The first cathodes were of similar dimensions and were made of one-fourth-millimeter iron-wire cloth of 30 meshes to the linear inch. I afterwards found that such cathodes offered too much resistance to the current and finally made them of about one-half-millimeter wire cloth of 16 openings to the linear inch. Such a piece of wire cloth has almost exactly the

same area for the submerged wires as would be presented by a solid sheet of metal of the same cross section exposed on both sides.

It is well known that when oxidation is desired in electrolysis a large anode area should be used. When reduction is wanted a large cathode area should be used. As reduction rather than oxidation was the purpose of the process it seemed wise to have a larger area of cathode than of anode. Hence, five such cathode sheets were fastened together and brought into contact with a copper conductor, above the water level, by crimping them at the top by a fold of sheet iron and at the bottom by similar small sheet-iron crimps. This makes what I term herein "bunches of five." After various trials I found that two such "bunches of five" cathodes, ten sheets in all, could be effectively inserted between each pair of anodes. The metal then deposits on all of the ten, most of course on the sheets next to the anodes, but upon all in time. These cathodes were three-sixteenths inch thick at the crimps and one-quarter inch at the widest part. The anodes were insulated from the cathodes by vertical rubber bands one-eighth inch thick. This arrangement was compact, giving over five times as much cathode as anode area. Since wire cloth, as manufactured, is coated with a protective coating of oil, it was always necessary to burn this off at a red heat before constructing the electrodes. To avoid undue oxidation, this burning must be done with care, particularly when the wire cloth is to be used for cathodes. A slight film of black magnetic oxide on the anodes is an advantage rather than a detriment, as it partly protects them from attack by the solution. With solutions free from salt and soluble sulphates the iron anodes are hardly attacked. Some of these anodes and cathodes that have been in use at intervals for 14 years are still serviceable.

Another advantage of the wire-cloth cathodes is that a dense current can be used without forming a loose deposit, and hence a rapid deposition can be obtained. The deposited metal tends to form about the wire a tube, which adheres firmly. This has long been recognized in the electrolytic assay of copper, where the use of platinum-wire gauze has so much reduced the time necessary for complete precipitation.

The advantages of the use of wire-cloth cathodes were as follows:

1. Direct and effective circulation of the solution from anode to cathode.
2. Larger area of cathode than of anode.
3. Use of a denser electric current without waste.

All of these advantages were not appreciated at once, but became gradually of more apparent importance as the investigation went on. The first experiments were tentative, and though the methods used were rather crude, compared with later ones, I give them rather fully because of the importance of the details.

PRELIMINARY EXPERIMENTS.

On September 17, 1900, I took a box $28\frac{1}{2}$ centimeters long by 6 centimeters deep and 7 centimeters wide, and holding 1.195 liters (0.0422 cubic foot) of liquid. In this were placed eight anodes made of sheets of 8-mesh iron-wire cloth, of wires 1 mm. in diameter. The nine cathodes were made of iron-wire cloth of 30 meshes to the linear inch. The immersed area of the cathodes was $6\frac{1}{2}$ square inches, or 0.0476 square foot. The actual surface of the cathodes was approximately double that area, or $13\frac{1}{2}$ square inches (0.0952 square foot). I used 8 liters of solution of 0.2 per cent KCy, assaying 15.87 mg. of silver per 100 c. c.

At 3.40 p. m. the first experiment was started, the current being 0.20 ampere, at 1.1 volts, and the solution containing 0.19 per cent KCy and 15.87 mg. of silver per 100 c. c. The source of current was a storage battery of 2 volts on an open circuit. Some resistance was used in series with the battery to adjust the voltage. At 5 p. m. the solution had passed through the box once, and the current was found to be 0.16 ampere at 1.25 volts, the solution containing 0.18 per cent KCy and 5.61 mg. of silver per 100 c. c. The recovery in the one passage through the box was therefore 64.50 per cent.

During this experiment no evolution of gas at the cathodes was visible or audible. After the first run had been finished, 8.4 c. c. of nitrate of silver, or 0.084 gram of silver, got into the solution by accident. In order to neutralize this, a proper proportion of cyanide of potassium was added to the solution. This increased the original assay value of the solution to 16.98 mg. of Ag per 100 c. c. The solution was then left at rest over night, with the battery connected. The voltage rose to 1.75, and the current fell to 0.06 ampere, and by morning the content of Ag had been reduced to 0.30 mg. per 100 c. c.

At 9.25 a. m. the solution was started a second time through the box. The voltage was 1.75 volts and the current 0.10 ampere. The solution had all passed through at 1.30 p. m. The silver had been reduced to 0.74 mg. per 100 c. c., showing that there had been precipitated, in the first and second run, 95.64 per cent of the original content.

At 2.10 p. m. the third run was begun at 1.75 volts and 0.2 ampere. The run was finished at 2.50 p. m. The solution contained 0.16 per cent KCy and 0.54 mg. of silver per 100 c. c. The recovery was 96.82 per cent.

At 2.55 p. m. the fourth run was started at 1.8 volts and 0.35 ampere. The solution contained 0.16 per cent KCy and 0.29 mg. of silver per 100 c. c. The recovery was 98.29 per cent.

At 3.18 p. m. the fifth run was started and was finished at 3.35 p. m. The solution contained 0.16 per cent KCy and 0.20 mg. of silver per 100 c. c. The recovery was 98.82 per cent.

At 3.39 p. m. the sixth run was started and was finished at 5.14 p. m. The solution contained 0.15 per cent KCy and 0.09 mg. of silver per 100 c. c. The recovery was 99.47 per cent.

A résumé of the results during the total period of 8.3 hours follows:

Results of early experiments with electrodeposition of silver.

Run No.	Duration of run.	Recovery.	Silver re- maining in residue.
	<i>Hours.</i>	<i>Per cent.</i>	<i>Per cent.</i>
1.....	1.55	64.50	35.50
2.....	4.08	95.64	4.36
3.....	.66	96.82	3.18
4.....	.40	98.29	1.71
5.....	.28	98.82	1.18
6.....	1.55	99.47	.53

Some solution was consumed in the samples, but, making no allowance for this, 8 liters of solution was treated, the silver content being reduced to 0.53 per cent in 8.30 hours. The box held 1.2 liters of solution, but the electrodes occupied somewhat less than 1 liter of this space, so that the solution was treated at the rate of about 1 liter per hour in a 1-liter box, the silver recovery being 99.47 per cent. Thus the capacity of the box, with wire-cloth electrodes, was 24 liters per 24 hours, or nearly five times the capacity with the plain electrodes used in my experiments at Bodie. The solution of 8 liters passed through the box six times in the 8.3 hours, or roughly speaking, it required 1.4 hours for 8 liters to pass once, and hence it required on an average 1.75 hours for 1 liter to pass through the box. The average rate of flow through the box was 5.7 liters per hour.

CIRCULATION OF SOLUTION.

The importance of a proper rate of flow through the box is evident from the following notes taken during the first run:

12.30 p. m.—Volts, 1.60; amperes, 0.120; solution in circulation.

12.45 p. m.—Circulation stopped; voltage at once raised to 1.73; amperes fell to 0.070.

1.00 p. m.—Volts, 1.74; amperes, 0.068; solution at rest.

1.30 p. m.—Volts, 1.75; amperes, 0.060; solution at rest.

2.10 p. m.—Solution started through the box for the third time; volts, 1.75; amperes, 0.200.

In all the experiments, when the circulation of the solution was stopped, the current dropped, and the voltage rose. The solution was made to circulate by hand, and after having passed through the box once it was placed again at the head and allowed to flow again, the rate being regulated by the stopcock. The results from the first run indicated that I was on the right track to increase the capacity of

the box, and the subsequent experiments were undertaken to determine the best conditions.

In all my first experiments the circulation was made by hand, as described; but it soon became evident that a rapid rate of circulation was so important that some automatic means ought to be used. For the purpose a small crude centrifugal pump like that shown in figure 5 was made.

A number of persons have tried to verify my results on a small scale without using a proper means of circulation. Centrifugal pumps as small as that shown are not to be purchased and it is

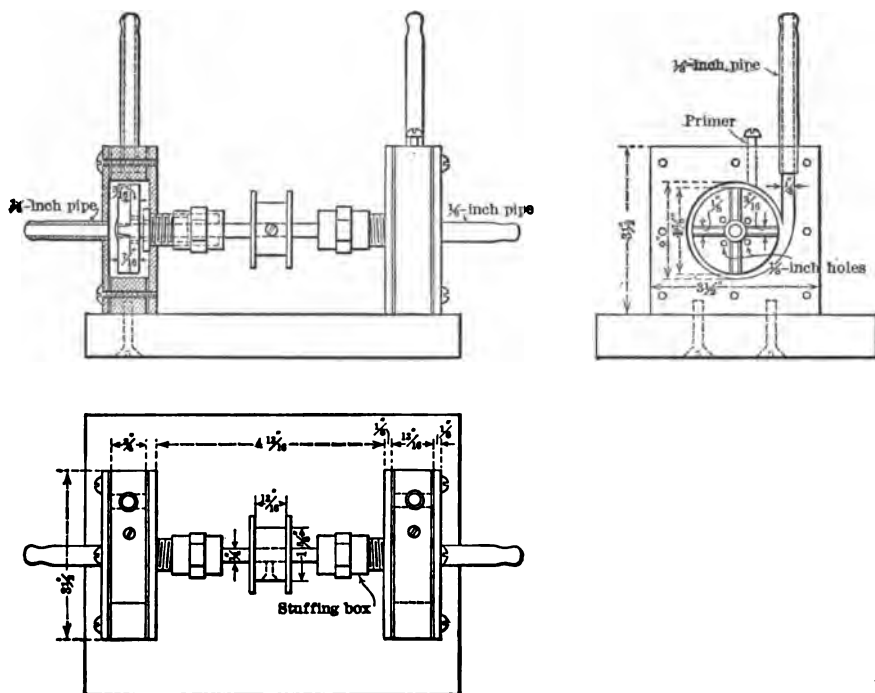


FIGURE 5.—Small double centrifugal pump used in circulating solutions.

necessary to make them, but they need not be elaborate or costly. The small double centrifugal pump shown can easily be constructed in any machine shop at small expense. It gives ample circulation for electrodes 10 by 10 cm., or 4 by 4 inches. This size is most convenient, as it has a sectional area of one one-hundredth square meter or one-ninth square foot, and results can be converted into square meters by multiplying by 100 or into square feet by multiplying by 9.

Two pumps are easier to use than one because they run in better balance (see fig. 5). The pumps rest in a planed base of cast iron 1

PRELIMINARY EXPERIMENTS.

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During this experiment no evolution of gas at the cathodes was perceptible or audible. After the first run had been finished, 8.4 c. c. of a solution of silver, or 0.084 gram of silver, got into the solution by accident. In order to neutralize this, a proper proportion of cyanide of potassium was added to the solution. This increased the original assay value of the solution to 16.98 mg. of Ag per 100 c. c. The solution was then left at rest over night, with the battery connected. The voltage rose to 1.75, and the current fell to 0.06 ampere, and by morning the content of Ag had been reduced to 0.30 mg. per 100 c. c.

At 9.25 a. m. the solution was started a second time through the box. The voltage was 1.75 volts and the current 0.10 ampere. The solution had all passed through at 1.30 p. m. The silver had been reduced to 0.04 mg. per 100 c. c., showing that there had been precipitated, in the first and second run, 95.64 per cent of the original content.

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inch thick. The body of the pump is a square block of cast iron three-fourths inch thick, planed true and faced on each side with graphited rubber gaskets. In the center of this plate a 2-inch hole is provided. The sides are of thin plates of iron, the outside ones carrying a one-eighth-inch suction pipe having the end turned for a hard-rubber hose attachment. The inner side carries a bearing, with stuffing box. The whole is secured to the inner plate by a lock nut. The packing is well lubricated with a mixture of vaseline and graphite, and should be adjustable to prevent leakage. It is important that the shaft through the stuffing box should be perfectly smooth so as not to cut out the packing. A pulley of thirteen-sixteenths-inch face, slightly crowning, and of $1\frac{1}{8}$ -inch diameter, is driven by a small electric motor or a Pelton water wheel. The runner is constructed with four blades and commonly should be placed in a position to be slightly eccentric, and tangent only near the discharge. The position of tangency most desired is not indicated in the particular pump here shown. The clearance elsewhere should be slight. It is important, too, to drill at least four one-eighth-inch holes through the web of the runner to allow it to run in balance. A one-fourth-inch drill hole leads the discharge to a one-eighth-inch pipe with a hose connection at the end.

It is astonishing how important a small pump of this kind is. Hand circulation is impracticable. Air lifts produce an aerated solution that tends to dissolve the gold. The pump shown, easily and cheaply made, has sufficed for thousands of experiments and is still in good order. Of course, for work on a large scale, a well-designed centrifugal pump would be necessary.

EFFECTS OF INCREASING THE RATE OF FLOW.

Most of the following experiments were conducted with solutions of pure silver potassium cyanide (KAgCy_2), which was cheap and convenient. The solutions were highly concentrated and were afterwards diluted to form the free cyanide solution desired, to which also other pure chemicals such as KHO , or CaH_2O_2 , and KCy were added as necessary. When proper precipitation had been procured the silver content was again raised by adding the proper volume of the strong solution, after which the process was continued. Only in this way could the many variable factors be kept under control. By the use of the rigid electrodes and of proper insulating spaces the anodes and cathodes could be brought within one-eighth inch of one another with perfect safety. A more compact construction is well nigh impossible.

At first I gradually increased the rate of flow and found that the capacity of the box increased proportionally. The rate was first

increased to 8 liters per hour, being subsequently increased to 10, 30, 60, and finally 120 liters per hour. The space occupied by the electrodes was about 1 liter. Also it was found convenient to increase the volume of the solution to about 22 liters. The results of a number of tests follow:

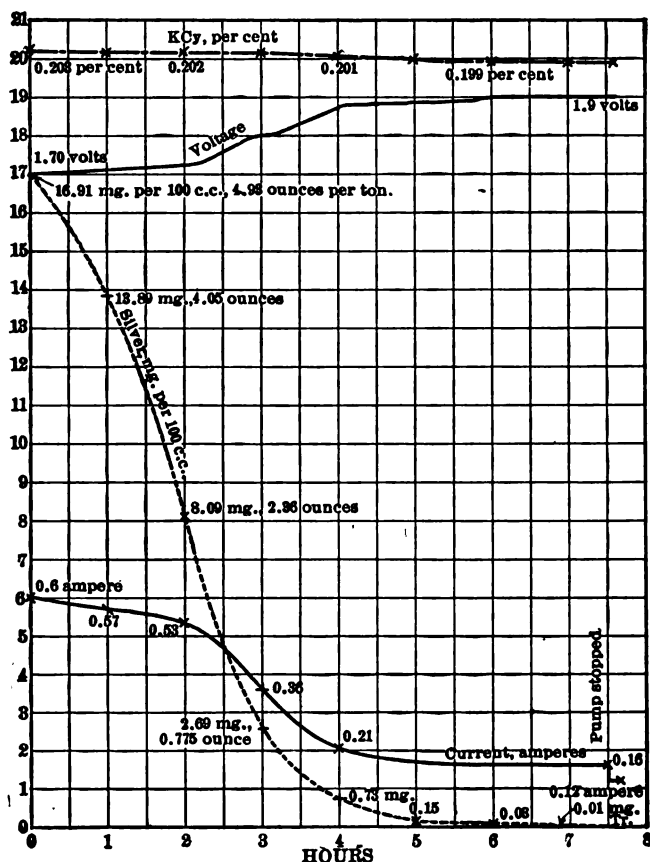


FIGURE 6.—Electrodeposition results with silver cyanide solution with rate of flow of 60 liters per hour; velocity, 9.4 inches per minute through open box, 21 inches through cathodes; 22 cathodes of 30-mesh iron wire, each $2\frac{1}{4}$ by $2\frac{1}{4}$ inches; area, 6.469 square inches; actual wire surface, 1 cathode, 0.1147 square foot, 22, 2.5234 square feet; estimated effective surface, 1 cathode, 0.1 square foot, 22, 2.2 square feet; 8 anodes of 8-mesh iron wire.

On October 5, 1900, I made an experiment with 22 sheet cathodes of 30-mesh wire cloth, and 8 anodes of 8-mesh wire cloth. The cathodes were $2\frac{1}{4}$ by $2\frac{1}{4}$ inches in size. The volume of the solution treated was 22 liters. The rate of flow was 60 liters per hour; the velocity of flow was 9.4 inches through the open box and 21 inches per minute through the cathodes. The estimated effective surface of one cathode was approximately 0.1 square foot, so that 22 cathodes

gave an effective surface of 2.2 square feet, and the actual surface of the wires was 2.52 square feet. The results of this experiment are shown in figure 6.

It will be noticed that there is a slow but continuous decrease in the value of the cyanide solution. The assay value of the silver begins at 16.91 mg. per 100 c. c., or 4.93 ounces per ton. The voltage is between 1.7 and 1.9 volts. Attention is called to the silver precipitation curve. The

fall of the silver is very rapid during the first three hours, during the next two hours it becomes slower, and after five hours it appears as an asymptote to the x axis, when the current is seen to be not economically used.

The effect of the increased rates of flow is shown in figure 7.

In the experiment here represented the rate of flow was increased to 120 liters per hour (velocity, 42 inches per minute through cathodes), or double that employed in obtaining the results shown in figure 6; other conditions were the same as in figure 6. It will be noticed that the silver was much more rapidly precipitated than in the previous

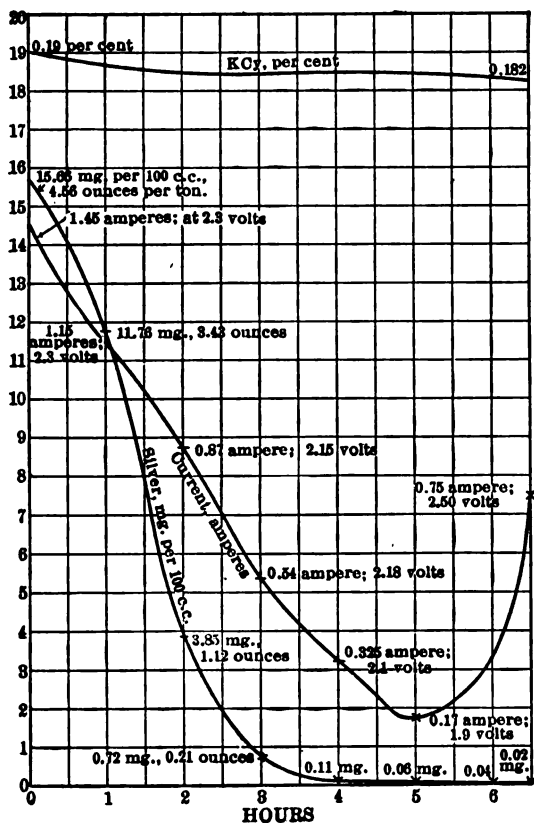


FIGURE 7.—Electrodeposition results with silver solution with rate of flow of 120 liters per hour; velocity, about 19 inches per minute through open box, 43 inches through cathodes; anodes and cathodes same as in figure 6. Voltage varied.

experiment. The voltage in this experiment varied between 2.1 and 2.5 volts. In spite of the high current density, there was no gas visible on either cathodes or anodes, so long as the solution was in circulation.

Figure 8 shows the results of an experiment similar to that represented in figure 7, except that the area of cathodes was increased. Twenty-two old cathodes of 30-mesh iron wire and two new cathodes, each consisting of 10 sheets of 1-mm. wire cloth, were used. The effec-

tive surface area of the cathodes was approximately 4.2 square feet, or twice that of the cathodes used for the previous test. In this experiment the voltage was controlled better than before. In the beginning 2.03 volts was employed, but after two and one-quarter hours the potential was raised to 2.5 volts, remaining thus until five and one-quarter hours had passed. At the end of the five and one-quarter hours a

new charge of KAgCy₂ was added, bringing the total volume again to 21.65 liters and replacing the solution used in the samples. It will be noticed that the current immediately rose from 0.6 ampere, which had been maintained by the 2.5 volts, to 1.45 amperes, and that the voltage fell to 2.35, showing that the solution had become a better conductor. It will also be noticed that the precipitation of silver was much better after a new charge had been added than before. Two hours after the silver solution had been added, the silver content had been

reduced from 17.38 mg. per 100 c. c. to 0.13 mg., or 0.038 ounce per ton. As stated above, the area of cathodes exposed was twice the area of the cathodes shown in figure 6. The precipitation capacity of the box had increased enormously. It was possible to make a new precipitation after adding a new charge of silver at the end of two hours.

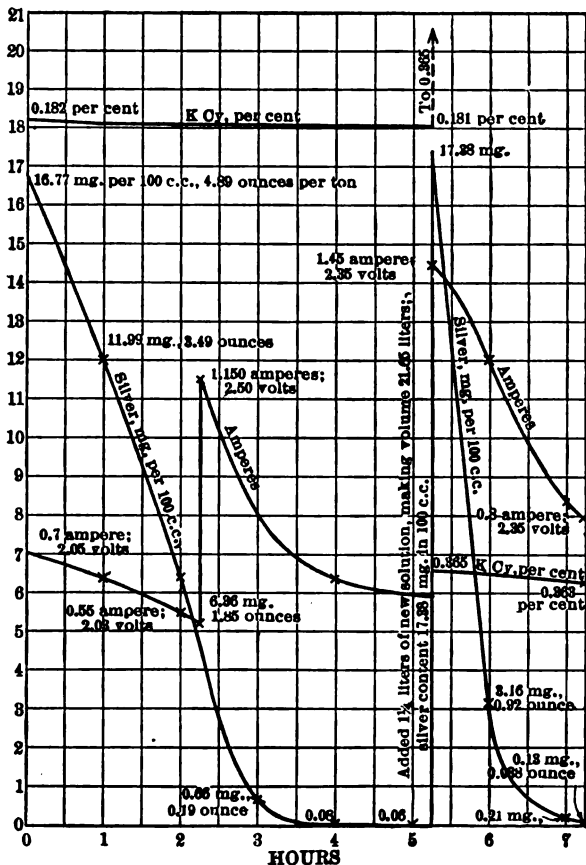


FIGURE 8.—Electrodeposition results with silver solution with rate of flow of 120 liters per hour and larger cathode area. Velocity of flow, 19 inches per minute through open box, 42 inches through cathodes; 22 used cathodes of 30-mesh wire cloth and 2 new cathodes, each of 10 sheets of 1-mm. wire cloth; actual wire surface of one cathode, — sq. cm.; estimated effective surface of 42 cathodes, 4.2 square feet.

Figure 9 shows the results of an attempt to increase the flow of solution to 180 liters per hour. The whole of the solution passed through the box nearly nine times in one hour, and as the box held about a liter, an amount equal to 180 times the volume of the box passed through in each hour. Forty wire-cloth cathodes and seven wire-cloth anodes were used in this experiment. The cathodes were 3.5 by 2.6 inches square and had a total surface area of 6.38 square feet. It

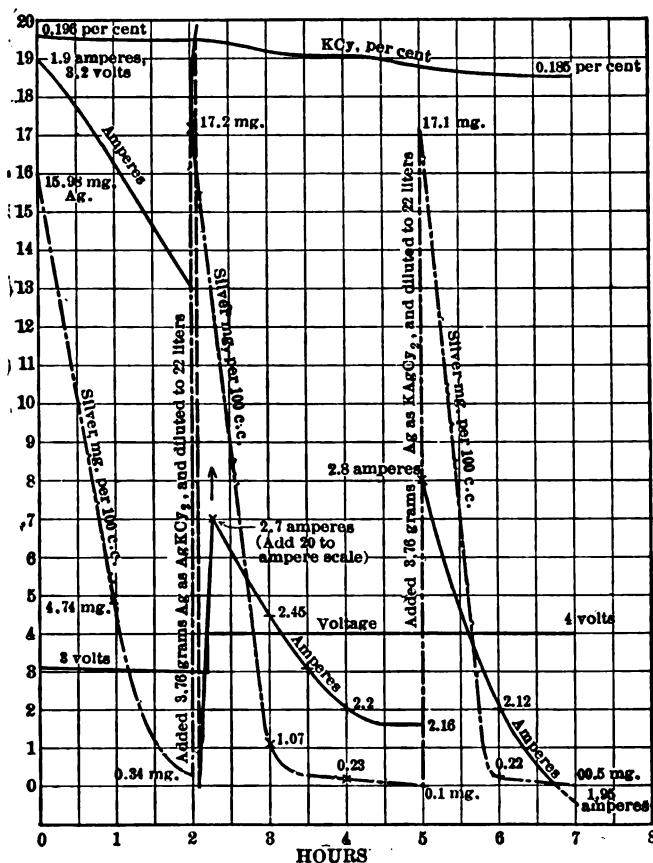


FIGURE 9.—Electrodeposition results with silver solution with rate of flow of 180 liters per hour; velocity, 20 inches per minute in open box, 45 inches through cathodes; 7 anodes of 8-mesh wire cloth; 40 cathodes of 30-mesh wire cloth; actual surface area, 6.38 square feet.

will be noticed that the precipitation curves show that the capacity of the box increased rapidly, a new charge being added at the end of two hours and another at the end of five hours. The voltage during the first two hours was 3, and during the rest of the time 4. The precipitation curves show successively better results.

As the precipitation became more effective, another feature noticed was that free cyanide was regenerated from the cyanide com-

bined with the precipitated silver. This feature was seen for the first time in the experiment represented in figure 10. In this experiment the flow of solution was increased to 300 liters per hour. The entire solution passed through the box 15 times in one hour. It will be

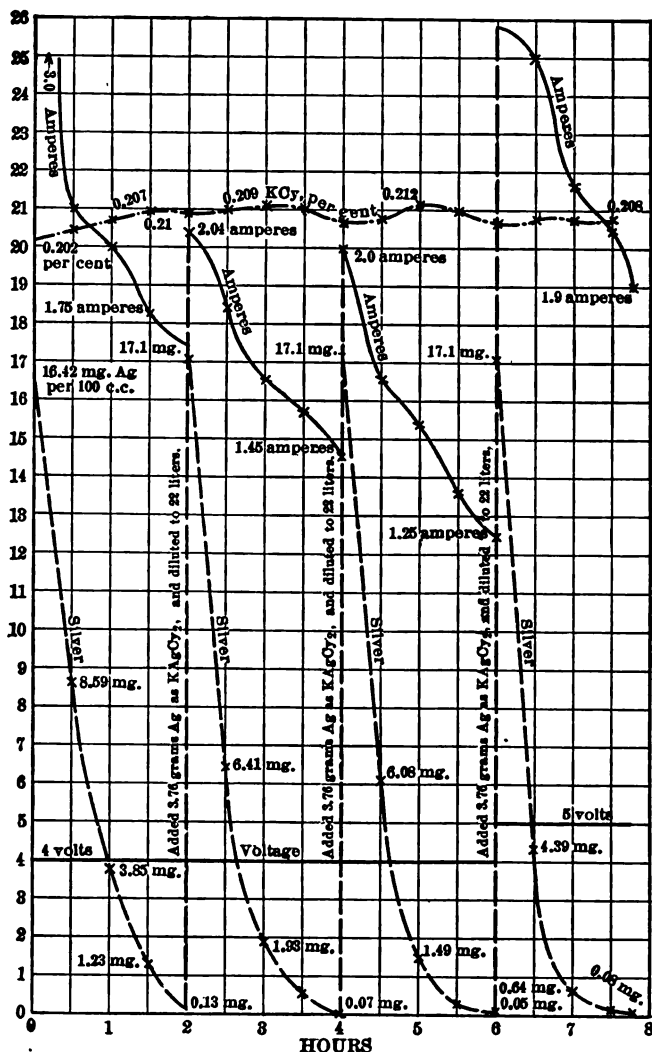


FIGURE 10.—Electrodeposition results with silver solution; rate of flow of 300 liters per hour; velocity through open box, 34 inches per minute; volume of solution, 22 liters; 7 anodes, 8-mesh wire cloth; 56 cathodes of 80-mesh wire cloth; wetted area, 3.5 by 2.6=9.1 square inches; actual surface area, 0.01773 square foot per square inch of cloth; for 56 cathodes, 8.936 square feet; length of electrodes, 5½ inches; volume, 47.7 cubic inches or 0.782 liter.

noticed that at the end of every two hours a new charge of $KAgCy_2$, with sufficient water to bring the volume up to 22 liters, was added

to the solution. The voltage was kept steady for the first six hours at 4, and during the last hour and a half was raised to 5 volts. It will be noticed also that the precipitation increased, especially between the sixth and seventh hours. The silver content and the current fell simultaneously, although the amperage did not fall quite as rapidly

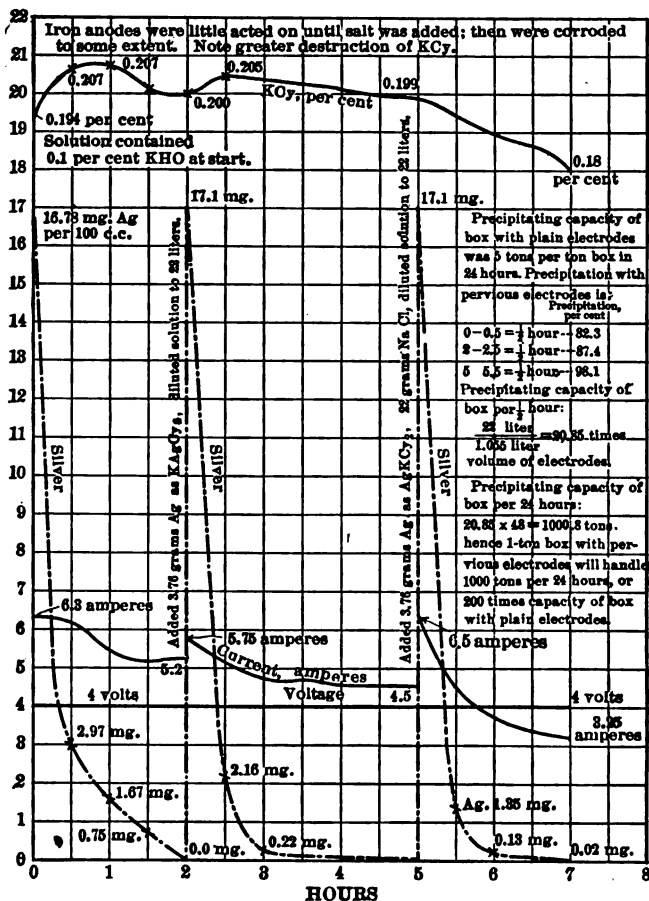


FIGURE 11.—Results of electrodeposition of silver with NaCl added to the solution; rate of flow, 300 liters per hour; velocity, 35 inches per minute through open box, 79 inches through cathodes; volume of solution, 22 liters; 11 anodes of 8-mesh wire cloth; 50 cathodes of 30-mesh cloth; total surface area, 5.735 square feet; length of electrodes, 18.75 cm.; volume occupied, 58.25 cm. or 1.055 liters.

as the silver content. It will be further noticed that during the rapid precipitation of the silver at the beginning of the experiment the solution contained 0.202 per cent cyanide, whereas at the end of one and one-half hours it had increased to 0.21 per cent. During the last half hour it fell again to 2.09 per cent. After a new charge of

KAgCy_2 , containing no free cyanide, had been added to replace the assay samples, the cyanide had again increased from 0.209 to 0.22 per cent, falling slightly again at the end of one and one-half hours, and rising each time a new charge of KAgCy_2 was added to the solution. There is no doubt about the titration of the cyanide.

The increase of cyanide during the precipitation period was seen still more clearly in the experiment represented in figure 11. The volume of solution and the rate of flow are the same as before. The number of cathodes is 50 and the voltage 4. Three charges of KAgCy_2 were treated, each containing 3.76 grams of silver. It will be noticed that during the first hour the cyanide had risen from 0.194 to 0.207 per cent, falling again in 30 minutes to 0.202 per cent as the silver was removed. When a new charge of silver cyanide was added it rose to 0.205, but fell at the end of three hours to 0.199 per cent. At the end of five hours a new charge of silver cyanide containing no free cyanide was added, together with 22 grams of salt. The salt was added to determine whether the increased conductivity of the solution, owing to the presence of the salt, would increase the rapidity of the precipitation. The salt did have somewhat such an effect. It will be observed, however, that there is a continued destruction of the cyanide by chlorine, resulting from the decomposition of the salt, which reduced the cyanide from 0.199 to 0.18 per cent.

CAPACITY OF BOX.

The estimated capacity of the box is shown in figure 11. The capacity of the box with plain electrodes without circulation, as already stated, was about 5 tons for a 1-ton box in 24 hours. In the first half hour, a precipitation of 82.3 per cent was obtained. In the first half hour of the second period a precipitation of 87.4 per cent was obtained, and in the first half hour of the third period the precipitation was 98.1 per cent. The volume treated was 22 liters, and the volume occupied by the 50 cathodes and 11 anodes was 1.055 liters. Dividing 22 by 1.055 we have for a half-hour period a precipitation capacity of 20.85 times the volume occupied by the electrodes, or 1000.8 for 24 hours. Clearly a box holding 1 ton, and fitted with electrodes as described, will handle over 1,000 tons in 24 hours. As a result of the investigation I was able to increase the precipitation capacity of the box filled with wire-cloth anodes and cathodes to more than 200 times that of a similar box with plain electrodes.

The effect of the increased capacity was shown still more strongly in the experiment represented in figure 12. The flow was increased to 720 liters per hour, and the voltage was increased to 9. The first treatment was for two hours, when 3.76 grams of silver was added to

USE OF PEROXIDIZED-LEAD ANODES AND WIRE-CLOTH CATHODES.

In the preceding tests an important difficulty was encountered. The precipitation capacity of the box had been increased so rapidly that the 30-mesh wire cloth became clogged with precipitated silver, which interfered with the circulation of the solution. The wire-

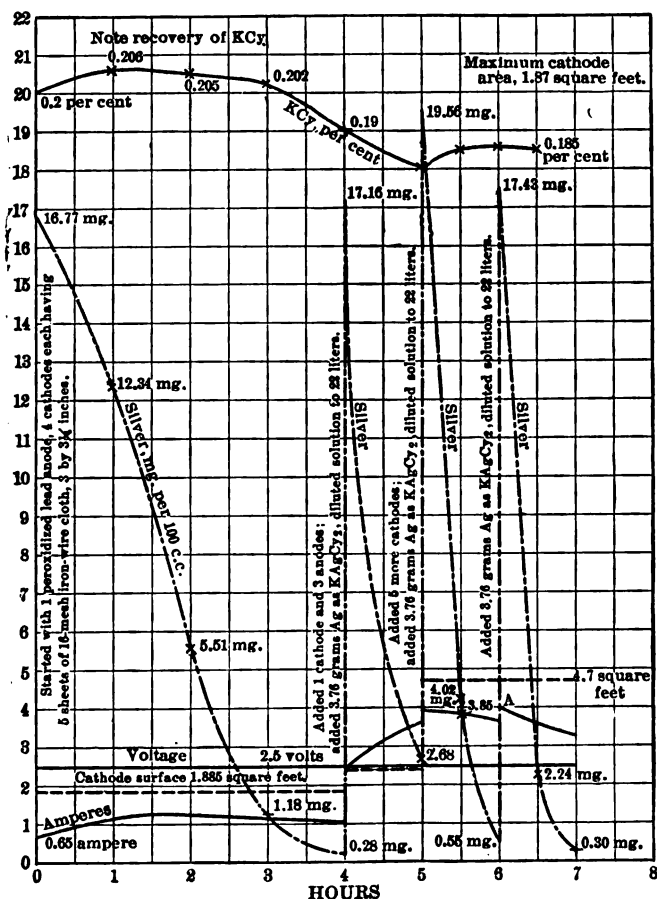


FIGURE 13.—Electrodeposition results with peroxidized-lead anodes and wire-cloth cathodes; volume of solution at start, 22 liters, containing 3.76 grams Ag as $KAgCy_2$, 22 grams KIO_3 , and 45 grams KCy ; rate of flow, 420 liters per hour; velocity through open box, 63 inches per minute; through cathodes, 142 inches.

cloth anodes also had become somewhat coated with ferric hydrate. An attempt was made to obviate these troubles.

I started with one peroxidized-lead anode, made of perforated sheet lead, and with four cathodes each formed from five sheets of 16-mesh iron-wire cloth, 3 inches wide and $2\frac{1}{4}$ inches deep in the solution, a new box having been made for the purpose. The rate of flow was 7 liters per minute, or 420 liters per hour. With only one

silver cyanide and water was added to make 22 liters. The cathode surface had been increased to 2.4 square feet and the precipitation was much more rapid than before. At the end of the fifth hour the number of cathodes was increased to 10 bunches of five each, or 50 in all. A new charge of silver cyanide was then added. The cathode surface having been increased to 4.7 square feet, the rate of precipitation had increased so rapidly that the silver content was reduced in 1 hour from 19.5 to 0.55 mg. per 100 c. c. A new charge of silver cyanide was again added, bringing the silver content up to 17.43 mg. per 100 c. c., but the precipitation of silver was so rapid that in 1 hour the silver content was reduced to 0.3 mg. per 100 c. c., or about 0.1 ounce per ton.

USE OF CARBON ANODES.

The next point tested was the effect of using carbon anodes, while employing the same box as before, and treating a solution similar in volume and content, but containing 10 per cent of 1 per cent caustic potash solution. The rate of flow was 6 liters per minute, or 360 liters per hour. The anodes were made of electric-light carbons, and in order to protect these from the action of oxygen they were soaked four days in melted vaseline. The form of the anodes was that of a comb, seven carbons being fastened together by means of a conducting strip of lead. The carbons, each three-eighths of an inch in diameter, were spaced one-eighth of an inch from one another and were immersed in the solution to a depth of $2\frac{1}{2}$ inches. There were 14 cathodes of five bunches each, formed of 16-mesh wire cloth, and having a total area of 6.59 square feet. The voltage was kept at $2\frac{1}{2}$. Precipitation curves for this experiment were obtained in a manner similar to those for previous experiments. The continued parallelism of the ampere curve and of the silver-precipitation curve is still observed. The cyanide recovery during the rapid precipitation of the silver, and the cyanide destruction after precipitation, are clearly shown in the curves. The carbon anodes were only slightly acted on, though the solution became of the color of weak tea. The solution, after having been aerated, showed no noticeable diminution of solubility for gold.

THE USE OF UNCOATED CARBON ANODES.

The next set of experiments was undertaken to determine whether or not ordinary electric-light carbons which had not been treated with vaseline could be used, and to determine the voltage required for effective precipitation. A set of the uncoated, electric-light, carbon-anode combs, such as have been described, were used, and also the same cathodes, in 14 bunches of five, making 70 in all. The cathodes were already coated with silver from the preceding experi-

ment. At first only 1 volt was applied, and instead of getting precipitation of silver, the silver already precipitated redissolved, as can be seen from the silver-precipitation curve in figure 15. The curve starts at 16.78 mg. per 100 c. c., and rises to 25 mg. per 100

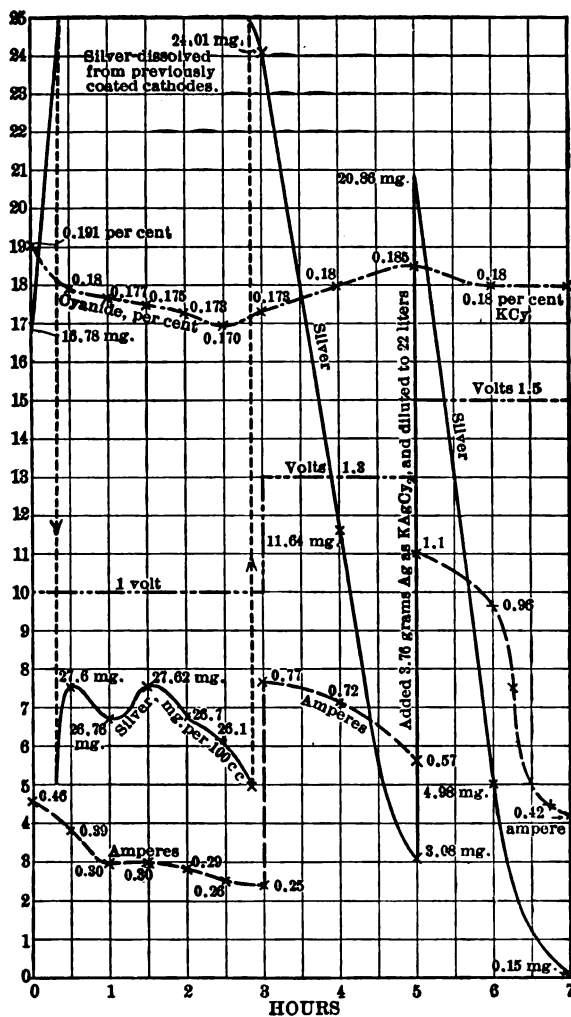


FIGURE 15.—Electrodeposition results with carbon anodes not coated with vaseline; 22 liters of water used, containing 44 grams KCy, 22 grams KIO₃, 3.76 grams Ag as KAgCy₃; rate of flow, 360 liters per hour; velocity through open box, 42 inches per minute; through cathodes, 96; 6 anode "combs" and 70 cathodes (same as in fig. 14) used; cathode area, 6.6 square feet. Owing to low voltage or poor contacts, some Ag was redissolved during first part of test and KCy absorbed.

c. c. in the first few minutes, then continues to rise and indicates 27.6 mg. per 100 c. c. at the end of the first quarter of an hour. The silver then decreased to 26.76 mg., increased again to 27.62, and fell again at the end of 2½ hours to 25. At the end of 3 hours the volt-

age was increased to 1.3 volts. At this point, the content of silver, which originally had been only 16.78 mg., had increased to 24 mg. With 1.3 volts, the silver began promptly to come down, and at the end of the next two hours the silver content had decreased to 3.08 mg. when a new charge of silver cyanide was added, bringing the content up to 20.86 mg. The voltage was increased to $1\frac{1}{2}$ volts, whereupon the silver was rapidly precipitated, being reduced in two hours to 0.15 mg., or about 0.05 ounce per ton. It will be noticed that during the whole time that silver had been dissolving from the cathode, free cyanide had been falling simultaneously. As soon as the silver began to be precipitated, it rose again, and at the end of the process, the cyanide content, which originally was 0.191 per cent, had fallen to 0.18 per cent. The experiment clearly shows that 1 volt is not sufficient for the effective precipitation of silver, that 1.3 volts is the minimum, and that a higher voltage than this is better.

EXPERIMENTS ON THE REGENERATION OF CYANIDE.

I have already called attention to the regeneration of the cyanide combined with the silver to be precipitated. The following experiments were undertaken to study the matter further. It was desired to avoid the oxidation of cyanide at the anode as much as possible; accordingly only $1\frac{1}{2}$ volts was employed. The solution used on a previous day was brought to a volume of 22 liters by adding the requisite amount of water. It then contained 0.189 per cent KCy and 0.1 per cent KHO. The rate of flow was 480 liters per hour. The electrodes occupied about 1 liter of space. The same anodes and cathodes were used as before (see fig. 14). The results of this test are shown in figure 16.

At the end of the first hour it is seen that the silver content had fallen from 17.36 mg. per 100 c. c. to 4.58 mg. leaving only about 1.74 ounces per ton in solution. Then a new charge of 3.76 grams of KAgCy_2 was added, and sufficient water to bring the volume back to 22 liters after the samples had been taken out. This brought the silver content up to 21.64 mg. per 100 c. c.

At the end of the second hour the silver content had fallen to 2.29 mg. per 100 c. c., or about 0.78 ounce per ton. A new charge of silver was added, as before, and at the end of the third hour the silver content had fallen to 0.74 mg. per 100 c. c., or 0.25 ounce per ton. A new charge was then added, and at the end of the fourth hour the silver had been reduced to 0.6 mg. per 100 c. c., or to 0.2 ounce per ton. A new charge of silver was then added, and at the end of the fifth hour the content had fallen again to 0.28 mg. per 100 c. c., or to 0.09 ounce per ton. A new charge was then added, and at the end

of the sixth hour the content had again fallen to 0.7 mg. per 100 c. c., or to 0.25 ounce per ton. A new charge was then added, and at the end of the seventh hour the content had been reduced to 0.33

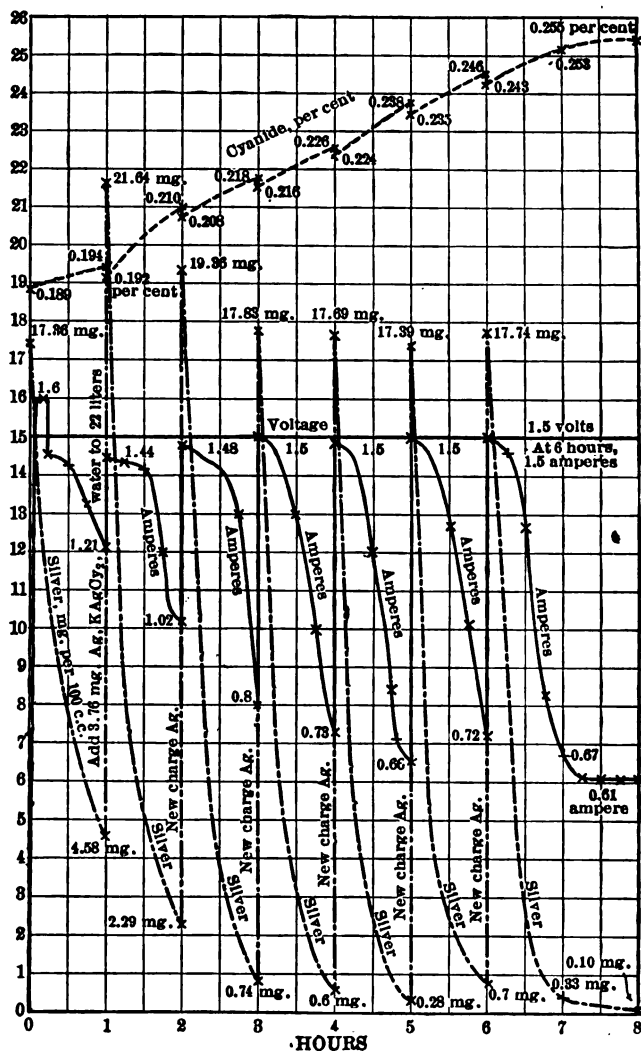


FIGURE 16.—Electrodeposition results showing regeneration of cyanide. Eight liters of water added to previously used silver cyanide solution to make up 22 liters, containing about 22 grams of KHO. Anodes and cathodes same as in fig. 15. Rate of flow, 480 liters per hour; velocity per minute through open box, 56 inches; through cathodes, 127. At 1, 2, 3, 4, 5, and 6 hours added 3.76 grams Ag as KAgCy and 0.25 liter of water to bring volume up to 22 liters. Note recovery of cyanide.

mg. per 100 c. c., or 0.11 ounce per ton. The test was continued for another hour, at the end of which time the silver in solution had been reduced to 0.1 mg. per 100 c. c. or 0.03 ounce per ton.

It will be observed that the cyanide titration shows a continuous rise in cyanide content. At the start the cyanide content was 0.189 per cent, and at the end of the first hour it had risen to 0.194 per cent, dropping again on account of dilution with water to 0.192 per cent. At the end of the second hour it had risen to 0.21, dropping again by dilution to 0.208. At the end of the third hour it had risen to 0.218, dropping again by dilution to 0.216. At the end of the fourth hour it had risen to 0.226, dropping again by dilution to 0.224. At the end of the fifth hour it had risen to 0.238. At the end of the sixth hour it had risen to 0.246, again dropping by dilution to 0.243. At the end of the seventh hour it had risen to 0.253, and at the end of the eighth hour it had risen to 0.255 per cent.

The total actual rise in the cyanide content, as shown by titration, was 0.066 per cent. If to this be added the amount of cyanide in the quantity of solution taken out for the assays, which was about 250 c. c. each time, the total saving of cyanide is 0.084 per cent. Multiplying this result by the weight of the solution, taken as 22 kg., gives an actual saving of 18.48 grams KCy, which was formerly combined with about 22.56 grams of silver. Taking the molecular weight of KCy as 130 and the atomic weight of silver as 108, if all the cyanide had been recovered there would be 1.2036 grams of KCy for every gram of silver precipitated. On this basis, as there was, roughly, 22.56 grams silver precipitated, there would be saved 27.07 grams KCy. The amount actually recovered was 18.48 grams, or slightly more than 68 per cent of the cyanide originally combined with the silver. It is evident, therefore, that all of this cyanide was not recovered, but a sufficient amount was saved to make this saving a highly important factor in the cost of precipitation.

It will be noticed that the curves representing the cyanide content all are rising where the silver is being rapidly precipitated. Between the sixth and seventh hour, and particularly at the end of the seventh hour, the curve of the recovered cyanide rises more rapidly than later, when the silver has been mostly precipitated. Toward the end of the experiment the destruction of cyanide begins to prevail over the regeneration, whereupon the curve rises more slowly, and finally begins to fall. This is caused by oxidation, which is constantly taking place at the anodes.

Attention is particularly directed to the parallelism between the fall of the ampere curves and those showing the precipitation of the silver. This is most clear between the sixth and eighth hours, where the ampere curve falls abruptly from 1.5 amperes. When the silver has fallen to 0.2 mg. per 100 c. c., and has been practically exhausted, as at the end of $7\frac{1}{4}$ hours, the ampere curve has fallen to 0.61. Here it remains constant during the rest of the experiment.

This phenomenon suggests a very simple method of controlling the precipitation without assaying the solution. If the voltage is maintained constant, the ampere curve shows the critical point at which it is best to stop precipitation. The point at which the ampere curve becomes constant is the most economical point to stop precipitation. At this point the recovery of cyanide reaches the maximum, and a further continuation of precipitation is wasteful of electric current.

During this test assay samples were taken every 15 minutes, but in practice sampling at longer intervals would suffice to correct the reading of the ammeter. This method of controlling the work I consider to be of great practical importance industrially, and the benefit can be gained only where a large volume of solution which is being rapidly circulated is treated, as here shown. The subject of cyanide regeneration is considered more fully in subsequent pages.

RUSTING OF IRON-WIRE CATHODES.

Attention should be called to another point that is evident in nearly all the later tests, but is also shown very clearly in the foregoing experiment. As the experiments were conducted intermittently and could only be carried on in the daytime, between the tests the wire-cloth electrodes became more or less rusted by the action of moisture on the wires, which were coated with silver. As is well known, under such circumstances a local action sets in, which causes rusting of the iron wire. When the cathodes were first immersed in the solution, much of the electric current was consumed in reducing this oxide of iron, and hence was not available for the precipitation of silver. It will be noticed that the precipitation improves during the continuation of the process. Other causes of this increase, aside from the dissolution of the rust, are that the conductivity of the solution gradually increases, owing to the presence of a larger amount of cyanide and other salts, and that the surface of the wire-cloth cathodes becomes covered with silver, making them better electrical conductors. From these three reasons it is evident that the rusting of the wire cloth will not take place whenever it is possible to have the process in continuous use.

TREATMENT OF RICH SILVER CYANIDE SOLUTIONS.

EXPERIMENT WITH SODIUM CHLORIDE IN THE SOLUTION.

The experiments hitherto described were conducted with silver solutions that were comparable in richness with those that occur in the treatment of ordinary ores. Experiments were next undertaken with a richer solution, containing 119.11 mg. of silver per 100 c. c. (see fig. 17), or about 41 ounces per ton. In other respects the solu-

tion treated was similar to those used before, consisting of 22 liters of 0.1 per cent free KHO, with 0.237 per cent KCy. In order to increase the conductivity of the solution, about 1 per cent of NaCl was added, and the circulation was at the rate of $9\frac{1}{2}$ liters per minute, or, 570 liters per hour. Six uncoated carbon anode combs were used; also 14 "bunches of five," or 70 in all, of the 16-mesh iron-wire cathodes, with a total area of 6.6 square feet. The voltage was 1.5.

Regeneration of the cyanide reached a maximum in this experiment at the end of two and one-half hours, when the cyanide content had risen to 0.295 per cent, after which it slowly declined to 0.273 per cent, owing to the action of chlorine and oxygen, set free at the anode. It will be noticed that there is again a close parallelism between the ampere curve and that of the rate of precipitation of the silver. Both curves change direction rapidly a little after three hours, the amperage falling from 2.57 to 0.70 at the end of that time, and the silver from 119.11 to 2 mg.

The effect of stopping circulation of the solution is shown at the end of three and one-fourth hours, at which time the belt on the pump accidentally broke. The current immediately dropped from 0.73 to 0.65, rising again to its place on the curve as

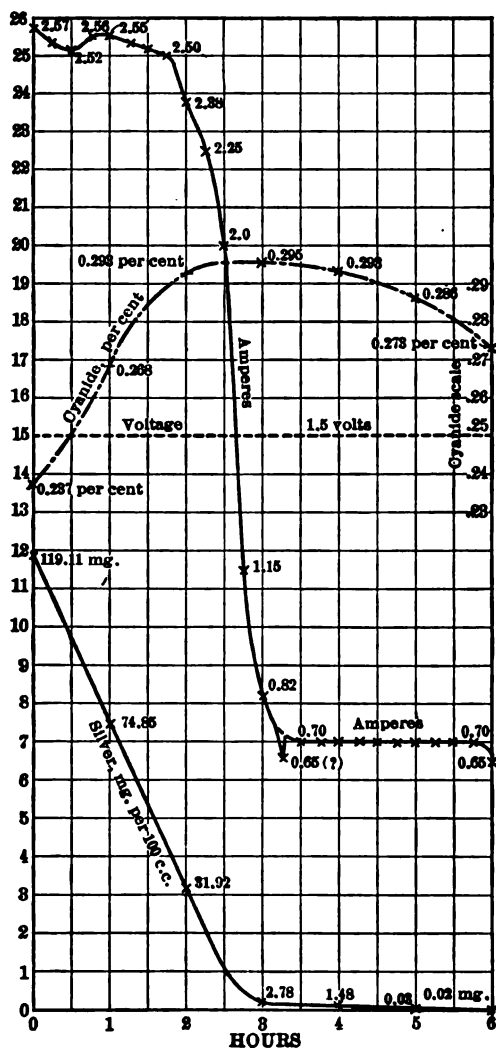


FIGURE 17.—Electrodeposition results with richer solution. Twenty-two liters of solution, containing 119.11 mg. of silver, 22 grams KHO, 220 grams NaCl, and 0.237 per cent KCy. Six uncoated "Electra" carbon anode combs. Cathodes, 14 bunches of 5 each, of 16-mesh wire cloth; total area, 6.59 square feet. Rate of flow, 570 liters per hour; velocity through open box, 68 inches per minute; through cathodes, 150.

soon as the pump was started. At the end of five and three-fourths hours, the circulation being maintained, the current was 0.70, and when the circulation was stopped it fell at once to 0.65.

EXPERIMENT WITHOUT SODIUM CHLORIDE.

In order to determine whether the use of salt in the solution was beneficial the experiment was repeated without salt. The same vol-

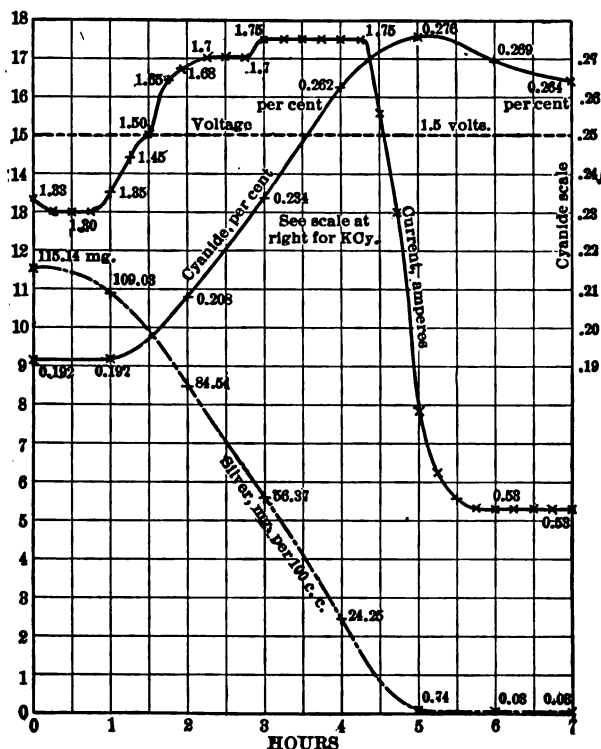


FIGURE 18.—Electrodeposition results with rich silver solution and no NaCl. Solution, 22 liters, containing 42.24 grams KCy, 25.33 grams Ag as KAgCy_3 , and 22 grams KHO. Rate of flow, 540 liters per hour; velocity per minute through open box, 63 inches; through cathodes, 141. Anodes and cathodes same as in figure 17; cathodes were coated with silver and rusted from standing over night after removal from the salt solution used in the previous test.

ume of solution, containing 0.1 per cent KHO and 0.192 per cent KCy and 115.14 mg. of silver per 100 c. c. was used. The flow was 540 liters per hour. The same cathodes, which had been coated with silver, were used as in the previous experiment (fig. 17). The results of the test are shown in figure 18. The ampere curve was decidedly different in form from that of the former experiment. It started at 1.33 amperes, falling in one-fourth hour to 1.30, then rising rapidly to 1.75 at the end of three hours. This value it main-

tained until four hours and twenty minutes of the total period had passed, when it fell precipitately until, at the end of five and three-fourths hours, it had become 0.53 ampere. There it remained constant until a total of seven hours had passed, when the experiment was stopped. It will be noted that the increase of cyanide content did not begin until one hour had passed, when it rose from 0.192 to 0.276 per cent. At this point most of the silver had been precipitated. At the end of five and one-half hours the cyanide content began to fall, and at the end of the test was 0.264 per cent.

It is evident from a study of these curves that the experiment should have been stopped at the end of five hours, when the recovery

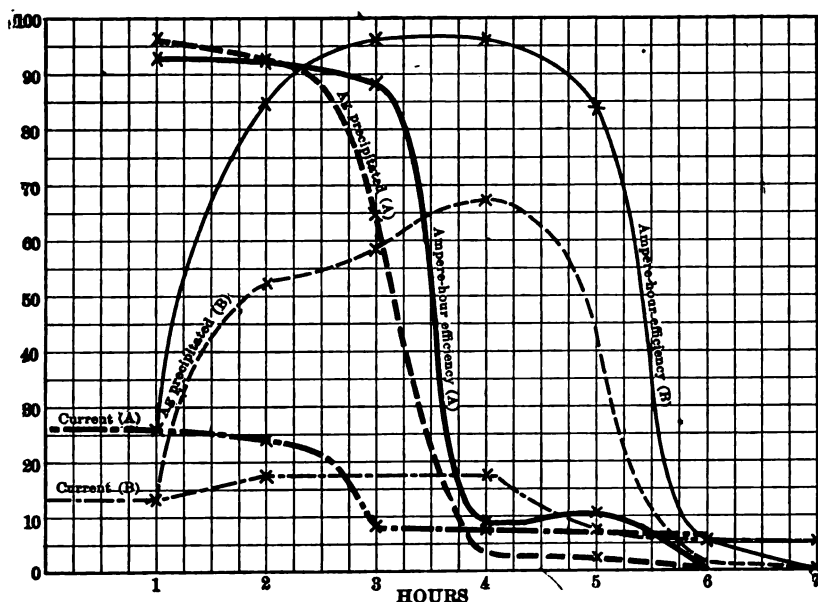


FIGURE 19.—Results of tests with and without use of salt compared. A, curves from test shown in fig. 17, salt used. B, curves from test shown in fig. 18, no salt used.

of cyanide was at the maximum. After that time the current was not used economically, and little silver was precipitated. The irregular rise of the current was evidently due to the rusting of the cathodes, which had stood over night wet with salt solution. The silver did not begin to come down rapidly, and the cyanide to be regenerated, until this rust had been reduced by the current. If the cathodes had been perfectly free from rust no doubt the current would have started at about 1.75 amperes, and would have remained nearly constant, and the silver would have been precipitated much earlier in the experiment. The voltage and amperage were read every 15 minutes with Weston standard meters. At the start and at the end of each hour a 250-c. c. sample was taken for cyanide titrations and for silver

assays. It will be observed that the electrical efficiency was extremely high as long as there was any silver to be precipitated, but that it fell rapidly when the silver content became diminished. The relative efficiency in the two tests is best shown in figure 19.

COMPARISON OF RESULTS.

If, neglecting the oxidation at the anode, we assume that the silver is precipitated at the cathode by the potassium ion, then for every atom of silver precipitated there will be two molecules of KCN set free at the cathode. Assuming 65 as the molecular weight of KCN, for every 108 grams of precipitated silver 130 grams of KCN should be regenerated, or $\frac{130}{108}=1.2036$ grams of KCN regenerated for each gram of silver precipitated. Evidently, notwithstanding the initial resistance to the current due to the rusting of the anodes, the final efficiency of both the silver precipitation and the cyanide regeneration was better in the second experiment, shown in figure 18, than in the first, shown in figure 17. In the first experiment the highest silver efficiency was 93.62 per cent, whereas in the second it was 96.35. In the first the highest cyanide regeneration was 58.19 per cent, but in the second it rose to 76.67 per cent. Evidently the addition of sodium chloride is not justifiable. The irregularity of the curves in the second experiment was also due to this cause.

THEORY OF ELECTROLYTIC CYANIDE REGENERATION.

The theory of electrolytic regeneration of cyanide is of great practical importance and is difficult to explain in a few words. According to the modern view the ions that carry the current in the solution exist already dissociated, or, at most, loosely associated. The electric current, accordingly, has only to direct their motion. The anode, being the positive pole of the cell, attracts the anions, each of which carries a negative charge to the anode where it gives up its negative charge. Simultaneously the cathode, being the negative pole of the cell, attracts the cations, each of which carries a positive charge and delivers it to the cathode. By this means each of the ions travels through the solution a variable, relative distance dependent on the "transfer velocities." The velocities have been accurately measured by Hittorf and others for many electrolytes. They are not necessarily equal; often they are relatively quite different; but for simplicity let us assume that all are equal. The potassium cation and the chlorine anion in normal solutions of KCl have nearly equal values.

Let us first assume a solution containing ions arranged as shown in the following diagram:

	+		+		+		+		+		+	
	-		-		-		-		-		-	
1	2	3	4	5	6	7	8	9	10	11	12	13

In this arrangement the + sign represents, for example, the potassium ion with its positive charge, the - sign represents the chlorine ion with its negative charge. If into such a solution are inserted two platinum electrodes with + and - charges the equilibrium is disturbed and the anions with their negative charges move one place to the right toward the anode with its negative charge, and each cation moves one place to the left with its positive charge, toward the cathode with its negative charge. The arrangement then becomes as follows:

-		+		+		+		+		+		+
		-		-		-		-		-		
1	2	3	4	5	6	7	8	9	10	11	12	13

When the chlorine anion, with its negative charge, reaches the anode, it gives up this electrical charge and becomes gaseous chlorine which escapes. When the potassium cation with its positive charge reaches the cathode it gives up its positive charge and becomes metallic potassium, which by a secondary reaction decomposes the adjacent water and produces KHO which remains in solution and hydrogen gas which escapes as such. It will be noticed that the intervening solution remains unchanged in chemical composition and that the only chemical changes occur at the electrodes. The theory thus agrees with the facts first observed by Faraday.

As regards potassium silver cyanide, the potassium cation with its positive charge travels a little faster than the AgCy_2 anion with its negative charge. The difference of velocity is not great and the preceding diagram will suffice to explain the case. We have only to suppose the cation with the + sign to be potassium as before and the anion with the - sign to be not chlorine but AgCy_2 . There will then be an increase of one molecule of AgCy_2 at the anode and an increase of one atom of potassium at the cathode. Suppose that there also are evenly diffused through the solution other molecules of KCy , KHO , KAgCy_2 , not yet brought under the influence of the current. Then when a K cation reaches the cathode and gives up its positive charge

it finds KAgCy_2 there, which is more easily decomposed than water. A secondary action, shown in the equation following, is then supposed to ensue.



This reaction was first suggested by Hittorf to explain the smooth, silver deposit obtained from cyanides, in contrast with the loose crystalline deposit from other salts of silver, such as the nitrate, where the silver is directly deposited by the current.

It will be noted that after electrolysis two atoms of silver are removed from the solution at the cathode, one by electrolytic wandering to the anode, the other by the precipitating action of the cation. (As regards the nitrate there would be removed only the one atom directly precipitated in crystalline form by the electric current.)

Let us next suppose this process to be repeated at the cathode, and further, that throughout the solution, not yet affected by electrolysis, there is uniformly diffused 2 KCy in the free state, 2 KHO , and 2 KAgCy_2 . At the cathode there is, then, before electrolysis: $2\text{KCy} + 2\text{KHO} + 2\text{KAgCy}_2$, and after electrolysis (as 2 K ions appear): $2\text{KCy} + 2\text{KHO} + 2\text{KAgCy}_2 + 2\text{K} - 6\text{KCy} + 2\text{Ag} + 2\text{KHO}$. It is seen that there is a gain at the cathode of 4 KCy , free, for each 2 Ag precipitated.

Let us make a similar supposition concerning the solution at the anode. Before electrolysis the composition was, $2\text{KCy} + 2\text{KHO} + 2\text{KAgCy}_2$, and after two units of electricity have passed, it is $2\text{KCy} + 2\text{KHO} + 2\text{KAgCy}_2 + 2\text{AgCy}_2$, an increase of two molecules of AgCy_2 at the anode. Now as shown by Morgan, 2AgCy_2 easily splits up into $2\text{AgCy} + 2\text{Cy}$.*

The 2AgCy easily combines with 2KCy to form 2KAgCy_2 , and the 2Cy reacts with 2KHO to form H_2O , KCyO , and KCy , one half being destroyed by becoming cyanate, the other half being regenerated as KCy . Combining these reactions at the anode into one we have, after electrolysis, the following chemical substances: $4\text{KAgCy}_2 + \text{KCyO} + \text{KCy} + \text{H}_2\text{O}$. Hence at the anode there is a gain of two molecules of KAgCy_2 , one of KCyO , one of water, a loss of two molecules of KHO and two of KCy , and a gain of one molecule of KCy ; therefore there is a net loss at the anode of KCy . But there was a gain at the cathode of 4 KCy , hence the net result is a total gain of 3 KCy for each 2 Ag precipitated, and the weights of silver precipitated and cyanide recovered will be:

$$\frac{\text{Cyanide recovered}}{\text{Silver precipitated}} = \frac{3 \times 65}{2 \times 108} = \frac{195}{216} = 90.27 \text{ per cent.}$$

* Christy, S. B. Electromotive force of metals in cyanide solutions: Trans. Am. Inst. Min. Eng., vol. 30, 1900, p. 882.

If no cyanide were oxidized, for every part of silver precipitated there would be: $\frac{2 \times 65}{108} \times 100 = \frac{130}{108} \times 100 = 120.37$ per cent cyanide recovered. As will be seen later, by greatly increasing the cathode area as compared with the anode area, I have actually recovered free cyanide to the extent of 118 per cent of the weight of the silver precipitated.

The reactions with potassium auro-cyanide are exactly the same as with those of silver, AuCy_2 being substituted for AgCy_2 . (It is possible that auric-cyanides are formed at the anode to be afterwards reduced to aurous at the cathode.) As the atomic weight of gold is greater than that of silver, however, the relative weights of cyanide recovered from a given weight of gold will be $\frac{108}{197} = 0.55$ times the amount recovered by an equal weight of silver. Further, as gold solutions usually contain very little gold cyanide compared with those obtained in treating rich silver ores, the amount regenerated is seldom noticeable.

Theoretically, cuprous cyanide should permit a large regeneration of cyanide, owing to its low atomic weight. I have been unable to obtain certain proof of this regeneration in the few experiments I have tried. Mr. Hamilton, in experiments with the Butters process, claims to have obtained such evidence. I shall discuss this later. The facility with which both gold and copper form complex cyanides of higher valency at the anodes by taking on one or more Cy radicals possibly explains the greater difficulty of regenerating cyanide from them than from silver cyanides. With regard to possible regeneration of cyanide from potassium cyanate and sulpho-cyanate, as claimed by Clancy, I will say that many years ago I made some preliminary experiments on this subject and got some small traces of regeneration, but not enough to cause me to follow the matter further. The regeneration of cyanide up to 118 per cent of the weight of silver precipitated as previously described would seem to indicate that some of the cyanate must have been regenerated.

Evidently, there is the certain possibility of regenerating a large part of the cyanide combined with silver, particularly in the rich solutions. This gives to electrolytic methods a great advantage over the usual methods of zinc precipitation. But to take full advantage of such regeneration the silver precipitation must not be pushed too far, for when the silver is nearly gone, electric current is wasted in decomposing the water, and the nascent oxygen set free at the anode destroys more cyanide than is regenerated at the cathode, particularly when the surface of the anode equals or exceeds that of the cathode. Of course actual mill solutions contain many other substances than those I have supposed, and the reactions are much more complicated

than those I have outlined. The final result depends not only on the composition of the solution, but also on the voltage, the relative current density at anode and cathode, and even on the physical as well as the chemical nature of the cathodes themselves. The tendency of cyanogen molecules to combine with one another, forming paracyanogen, and to oxidize to azulmic acid is another complication, as is the tendency, which should be mentioned, of cyanide to deteriorate into K_2CO_3 and ammonia compounds. The presence of sufficient free alkali is of controlling importance in the regeneration of the cyanide.

CAN CYANIDE BE REGENERATED BY THE ELECTROLYSIS OF FERROCYANIDES?

Prof. Kern,^a of Columbia, in a report published in 1913, answers this question with an emphatic "No!" He says:

(12) The regeneration of cyanide solutions which contain sulphocyanide and ferrocyanide does not occur by electrolysis by direct current, whether the conditions of electrolysis be made oxidizing or reducing by varying the relative current densities at the anode and the cathode.

On March 14, 1901, I made a preliminary investigation to see whether there was anything in this idea. Twelve liters of a 1 per cent solution of K_4FeCy_6 , with 0.2 per cent KHO , was made up. It was circulated through the deposition box. Six hard carbon combustion anodes were used and 14 of the 5-cluster clean iron-wire cathodes.

The original solution was carefully titrated for KCy and appeared to contain a trace (0.001 per cent) of KCy , which possibly was produced by the action of the potash. The solution was clear and of a pale yellow color. It was electrolyzed for four hours at 1.5 volts, and 1.4 to 2.1 amperes. The solution changed in color, taking on a slightly greenish tinge, and traces of a deposit like Fe_3O_4 formed on the carbon anodes. Seemingly there was a very slight increase in the reaction for cyanide, but this was doubtful.

The carbon anodes were then removed and platinum was substituted for them. The voltage was increased to 2.5, and the current of 3.3 to 4.2 amperes was continued for one hour. No definite change was observed in the cyanide. A little ferric hydrate and Prussian blue formed on the anodes.

The voltage was then raised to 4, and the current increased to 8 amperes and was continued for one hour. The solution was now full of fine bubbles and had turned orange color, due probably to suspended ferric hydrate. A distinct reaction for cyanide was obtained, the titration showing 0.005 per cent KCy . The anodes were coated with ferric hydrate and Prussian blue. In 20 minutes more

^a Kern, E. F., Electrolysis of cyanide solutions: Trans. Am. Electrochem. Soc., vol. 24, 1913, p. 265.

the KCy content rose to 0.007 per cent, and one hour later to 0.019 per cent. The entire solution was full of minute bubbles of gas, the composition of which was not determined. Also, loose flocculent ferric hydrate was contained in suspension. Of the original sample, which titrated 0.001 per cent KCy before electrolysis, 22 c. c. was inclosed in a tube with 12 c. c. of air and with a standard gold strip 2 inches by one-fourth inch in size, weighing 0.25 gram. The gold strip was then rotated for one hour in the solution, after which time it was found to have lost in weight 0.25 mg. gold. The solution therefore must have contained a trace of cyanide produced by the dissociation of the ferrocyanide in the presence of the KHO.

A similar experiment was made with 22 c. c. of the clear solution (titrating 0.019 per cent KCy), taken at the end of the electrolysis, and 12 c. c. of air. Both tubes containing the gold were rotated on the same shaft for one hour side by side. Upon weighing the gold, the loss from this second strip was 4.05 mg., or more than 16 times that from the first strip.

The gold strips were then reversed, the second being placed in the original solution and the first in the residual solution. The former now lost 0.04 mg. and the latter 0.94 mg. A film, not visible to the eye, seemed to have formed on both gold strips, but the electrolyzed solution was still leading, being this time 23.5 times as effective as the original solution. It would appear from these experiments that with platinum electrodes, at least, cyanide can be regenerated from potassium ferrocyanide in the presence of caustic potash, with a current of moderate density. This would give a great advantage to electrolysis if it could be made generally applicable. However, I did not follow the matter further.

Although Kern denies the possibility of any regeneration from the ferrocyanide by direct current, he says:*

When cyanide solutions containing sulpho or ferrocyanide were electrolyzed, the cyanide consumption was much less than that which occurred in pure cyanide solutions, which indicates that sulphocyanide and ferrocyanide act as protective agents during the electrolysis of cyanide solutions.

It would seem that another explanation than that of "protective agents" is possible—namely, that there was actually a slight regeneration that partly offset the usual oxidation losses. The amount of cyanide that was regenerated in my test was slight. It was necessary to use 100 c. c. samples to be sure of the cyanide titration. However, there seems no doubt that under certain conditions a small amount of cyanide can be regenerated from the ferrocyanide by the direct current, and this factor is another possible advantage in electrolysis over zinc precipitation.

* Kern, E. F., work cited, p. 264.

SHEET-IRON ELECTRODES COMPARED WITH IRON WIRE-CLOTH ELECTRODES.

To determine whether the iron wire-cloth electrodes were actually superior to those of sheet iron, 12 sheet-iron anodes were made. These sheets, $3\frac{3}{4}$ inches high by 3 inches wide, were held by two hard rubber strips, one on each side, so extended as to keep the lower edge $\frac{1}{4}$ inch above the bottom of the box. The 12 sheet-iron cathodes were 4 inches high by 3 inches wide, in the clear, and were held in ebonite insulating strips. Four $\frac{1}{4}$ -inch perforations were made near the top of each strip to allow the solution to circulate. The cathodes were coated with a thin film of graphite and vaseline. The electrodes were $\frac{1}{4}$ inch apart. The effective cathode area was 1.25 square feet or about 0.12 square meter. Circulation was produced by the centrifugal pump, and the flow was up and down through the $\frac{1}{4}$ -inch by 3-inch spaces, at the rate of only 0.56 liter per minute in the beginning. The results were as follows:

Results of tests with sheet-iron electrodes.

Time, hours.	Volts.	Amperes.	KCy in solution, per cent.	Silver per 100 c. c., mg.
0	0	0	0.215	16.75
1	1.5	0.60-0.22	.214	13.99
2	1.5	.27	.214	12.06
3	1.5	.265	.213	10.43
4	1.5	.23	.212	9.13
5	1.5	.24	.210	8.65
6	1.5	.21	.209	8.25
7	1.5	.20	.209	6.86

The results (see fig. 20) at the end of the first hour were so poor that during the second hour the cathodes were removed, cleaned with gasoline of the graphite-vaseline mixture and of silver, and then replaced. At the end of the fourth hour the electrodes were placed parallel with the longer dimension of the box to increase the velocity of flow to 6 liters per minute. The experiment was repeated with many variations without graphite and vaseline, in which a voltage of 2 volts and a current of 1 ampere were employed, and also 2.5 volts and 3 amperes. With the stronger current the precipitation was very little better. At 0.95 ampere small bubbles of gas filled the solution and this gas increased with higher current densities. The advantage of the greater surface presented by the wire-cloth cathodes compared with that of the sheet-iron cathodes was evident.

COMPARISON OF SILVER CLEAN-UP FROM SHEET-IRON ANODE WITH CLEAN-UP FROM WIRE-GAUZE ANODES.

The clean-up box that was used held 500 c. c. of solution; the solution contained 0.1 per cent KCy. The voltage was not recorded;

from memory I judge that it was derived from one Daniell cell and was higher at the end than in the beginning. The anode was of sheet iron 8.3 by 8.7 cm. in size, giving an area of 144.2 square centimeters for the two sides. The current was 0.1 ampere at first, finally becoming 0.005 ampere. The sheets of silver that finally

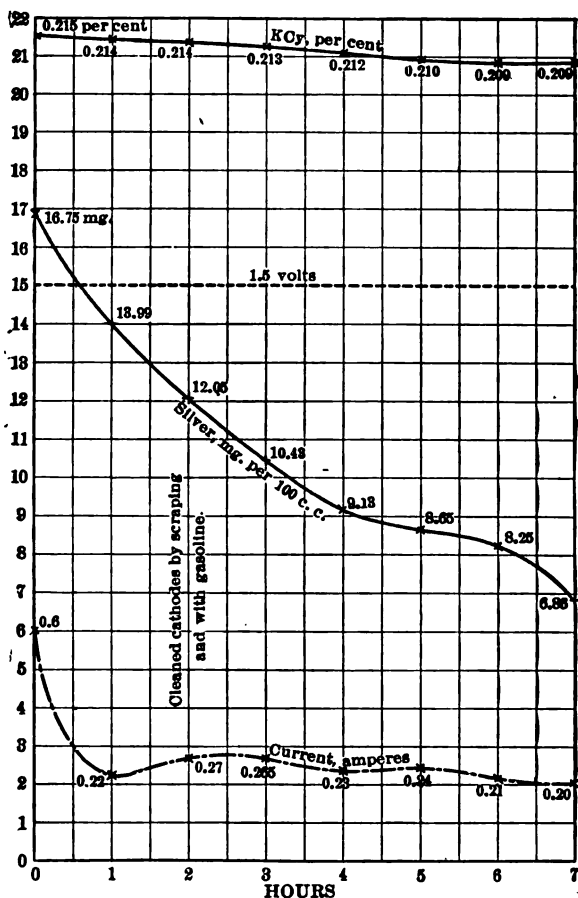


FIGURE 20.—Electrodeposition results with sheet-iron electrodes. Twelve anodes, effective area 1.25 square feet, and 12 cathodes, effective area 1.25 square feet, spaced $\frac{1}{4}$ inch. Silver cyanide solution, rate of flow 0.56 to 6 liters per minute. During first four hours, electrodes vertical, velocity of flow up and down slots averaged 0.68 inch per minute. After fourth hour, electrodes parallel with flow, velocity much increased. Figure 16 (p. 66), compared with this figure, shows advantage of using wire-cloth cathodes and larger area of cathode than of anode.

were peeled off were about 0.23 mm. thick; one weighed 19.78 grams and the other 16.85 grams. To the total weight of the sheet silver recovered, 36.63 grams, should be added that of the silver slimes from solution (0.39 gram), making a total of 37.02 grams. The residual cyanide solution, which was a deep yellow, contained

0.065 per cent free cyanide and 0.153 gram iron per liter. Half of this weight of iron had dissolved from the anode.

Another clean-up was made during which the stripping solution was made to circulate through the clean-up box. The cathode used was $2\frac{1}{4}$ by $3\frac{1}{4}$ inches in size, giving an area for the two sides of 19.26 square inches or 0.134 square foot. With 10 wire-cloth wire cathodes in two bunches of five, connected as anodes on each side of the cathode, 1 Daniell cell gave 0.25 ampere. When the solution was strongly circulating, the current rose to 0.35; on the circulation being stopped, the amperage fell in one minute to 0.1 and the voltage rose to 0.7. Finally the current fell to 0.2 ampere, and the cyanide content to 0.25 per cent; and the solution contained 29.73 mg. of silver per 100 c. c. The solution was now strengthened to 0.45 per cent free KCy and the voltage was raised to 1.25, when the last two bunches of five cathodes from the deposition box were put in.

The current density was at first 2.61 and finally 0.373 ampere per square foot. This density was too high except when the rate of circulation of the solution also was high. About 50 mg. of fine silver dust came off in washing, and only 10 mg. were found in the clean-up box. The final solution contained 0.41 per cent KCy and 3.55 mg. of silver per 100 c. c. The cathodes were apparently stripped clean. The amount of silver recovered from the cathodes was as follows:

Quantity of silver recovered from cathodes.

	Grams.
From 1st set (4×5) of cathodes-----	7.700
From 2nd set (4×5) of cathodes-----	5.977
From 3rd set (2×10) of cathodes-----	2.258
Total recovery -----	15.935

The solution treated in the deposition box contained 15.040 grams of silver, giving an excess recovered of 0.895 gram, which came from the original cathodes that were not entirely cleaned in the previous test. The silver recovered was entirely free from gold, copper, or iron, and was decidedly fine. The silver dissolved in nitric acid, leaving no residue, and the nitric acid solution gave no color test with ammonia.

THE USE OF THE CLEAN-UP BOX WITH RAPID CIRCULATION.

The capacity of the deposition box had now been so increased that it far exceeded that of the clean-up box, and I next tried to increase the capacity of the latter in the way that I had that of the deposition box. This was not easy, as it was desirable to use sheet cathodes from which the metal could be stripped.

The sheet-iron cathodes of the clean-up box were of two types, which will be designated as A and B. The surface of the type-A

cathodes exposed to the solution was 7.5 by 8.5 cm. These cathodes touched the bottom of the box, and were perforated near the top with four 6-mm. holes to allow the solution to pass through. The total submerged area of the six type-A cathodes was 765 square centimeters. The six type-B cathodes used were each 7.5 by 8 cm. in size. They were so placed that they did not quite touch the bottom of the box, in order to force the solution to pass under. The area of these six cathodes on both sides was 720 square centimeters. The total cathode area was thus 1,485 square centimeters, or a little less than one-sixth square meter, or about 1.5 square feet.

The vertical edges of the cathodes A and B were insulated by ebonite strips 1 cm. wide and 6 mm. thick, which were placed on each side of the plates to stiffen them and to prevent their touching the electrodes to be stripped. The plates were then rubbed with a mixture of graphite and vaseline, just enough vaseline being used to make the graphite adhere. This coating was rubbed to a dry finish and the cathodes A and B were placed in alternate positions to force a proper circulation of the solution. Between the 12 cathodes were placed the wire-cloth anodes to be stripped, which had been the cathodes of the deposition box. Thirteen to 26 of these could be stripped at a time. In the first experiment 14 were used. The solution was circulated rapidly through the box by a small centrifugal pump.

The 14 wire cathodes in bunches of five, to be stripped, had been used before and had an unknown quantity of silver deposited on them. In the present test four different lots of dilute cyanide solutions, containing silver, were deposited on them in the usual way. The depositions were continued at convenient intervals for several days, the cathodes being taken out and dried between times. The conditions of deposition were unfavorable to good precipitation, on account of the local action between the iron and the silver during the drying, which would not occur in continuous practice. In all 55.328 grams of silver was calculated to have been deposited on the cathodes in these four runs, the exact amount, however, being greater on account of the unknown amount on them in the beginning.

Stripping followed with one small "Nungesser" cell (zinc and copper oxide in NaHO) which gave a voltage of 0.75 in open circuit, but much less on a closed circuit. At first, with 12 cathodes and 14 anodes to be stripped, the cell gave 0.4 volt and 1.4 amperes on a closed circuit. This soon fell to 0.3 volt, but the current remained at slightly more than 1 ampere till the electrodes were nearly stripped (five hours), when the voltage rose to 0.58 and the amperage fell to 0.38. In seven and one-half hours the wire electrodes were apparently completely stripped, the voltage of the cell having risen

to 0.68 volt and the current having fallen to 0.2 ampere, the current density being 8.0 amperes per square meter at the start and about 1.11 at the end of the stripping. The silver formed a brilliant white deposit and adhered firmly. The only trouble was a tendency for the silver to creep on the edges of the ebonite strips where a little graphite had accidentally adhered.

The stripped anodes were then removed, washed, and dried, and the process of electroconcentration was again undertaken. The six type-A electrodes were now made anodes, and the B electrodes were made the cathodes. The voltage was varied from 0.2 volt at the start to 0.68 at the end. The current at the start was 0.96 ampere and at the end 0.062. The cell was run 22 hours, when the silver was found to be entirely removed and concentrated on the six B cathodes. It was found to be in beautiful coherent sheets that could be readily peeled off. The formation of these strips is a complete refutation of the statements of Prof. Neumann that this is impossible. The total weight of silver concentrated on the six B cathodes weighed 91.8 grams. The cyanide solution at first contained about 1 per cent KCy.^a To this more was added from time to time, and at the end of the test the content of free KCyⁱ was 0.41 per cent. The silver content at the end was 4.42 grams of silver in 1.25 liters of solution, or about 0.354 per cent. Of course it would have been easily possible to reduce this amount of residual silver to almost any smaller amount by electrolysis. In one test the silver content of the solution in the stripping box was reduced to 0.98 mg. per 100 c. c., the KCy content being 0.59 per cent. If the solution were to be discarded the silver value could be reduced to a few cents per ton by circulating the solution a few times through the deposition box.

These excellent results were repeatedly duplicated, and the good coating with this dense current would have been impossible without the rapid circulation of the stripping solution.

DEPOSITION OF GOLD ON IRON WIRE-CLOTH CATHODES.

The electrodeposition of gold from cyanide solution is both theoretically and practically more difficult than that of silver. Theoretically the difference is to be judged by the electromotive force determinations of these metals in cyanide solutions.^a Thus in 6.5 per cent KCy solution gold is electropositive to silver by 0.100 volt; in 0.65 per cent KCy solution, by 0.07 volt; in 0.065 per cent KCy solution, by 0.035 volt; and in 0.0065 per cent KCy, by 0.030 volt. This latter strength of solution is near the critical point at which both gold and silver become electronegative to cyanide solutions. Beyond

^a See Christy, S. B., electromotive force of metals in cyanide solutions: *Trans. Am. Inst. Min. Eng.*, vol. 30, 1900, pp. 921-2.

at point, while both metals remain electronegative, the silver becomes less so (less "noble") than does gold.

Practically the extent of the difference by which gold is less easily precipitated from cyanide solutions than is silver increases more than 3 figures would indicate. This is shown by a study of the following experiment.

DEPOSITION OF GOLD FROM GOLD CYANIDE SOLUTION.

At the beginning of the test there was 22 liters of gold cyanide solution, containing 0.198 per cent KCy, 0.1 per cent KHO, and 3.696 grams Au as KAuCy_2 . Fourteen bunches of five iron-wire cathodes were used. The flow was at the rate of 8 liters per minute, or 480 liters per hour. The mean area was 4 square feet. The results are given below.

Results of electrodeposition experiment with gold cyanide solution.

Hours.	Volts.	Amperes.	KCy, per cent.	Gold, mg. per 100 c. c.
0	0	0	0.198	16.80
1	1.5	2.00 to 0.6	.190	14.50
2	1.5	0.61 to 0.52	.191 (?)	5.92
3 ^a	1.5	0.52 to 30	.188	1.40
4	1.5	1.02 to 0.43	.182	.09
5	1.5	0.41	.174	.02
6	1.5	0.41	.165	Trace.

Note interruption of current for half an hour. Here the electric current failed, cathodes were removed and drained. After delay of one-half hour the current came on and the cathodes were replaced. The current was high at first, then dropped rapidly.

The ampere-hour efficiency, assuming gold as univalent, 7.35 grams per ampere-hours, was as follows:

Data showing ampere-hour efficiency.

Hour.	Gold, mg. per liter.		Liters treated.	Gold precipitated, grams.	Average ampere-hours.	Theoretical gold, grams.	Ampere-hour efficiency.
	In sample.	Difference.					
0	168.0						<i>Per cent.</i>
1	145.9	22.1	21.79	0.4816	1.12	8.2320	5.79
2	59.2	86.7	21.68	1.8800	.57	4.1897	44.87
3	14.0	45.2	21.57	.9750	.46	3.3812	28.71
4	.9	13.1	21.46	.2811	.56	4.1162	6.83
5	.2	.7	21.35	.0149	.41	3.0137	.49
6	Trace.	.2	21.24	.0042	.41	3.0137	.0139
				3.6368		25.9465	14.01

In the above experiment, the initial volume, 22 liters, was reduced 0.210 liter for the first sample and by 0.110 liter for each succeeding sample, taken at the end of each hour. Hence a deduction from the volume for the solution treated each hour is necessary. A num-

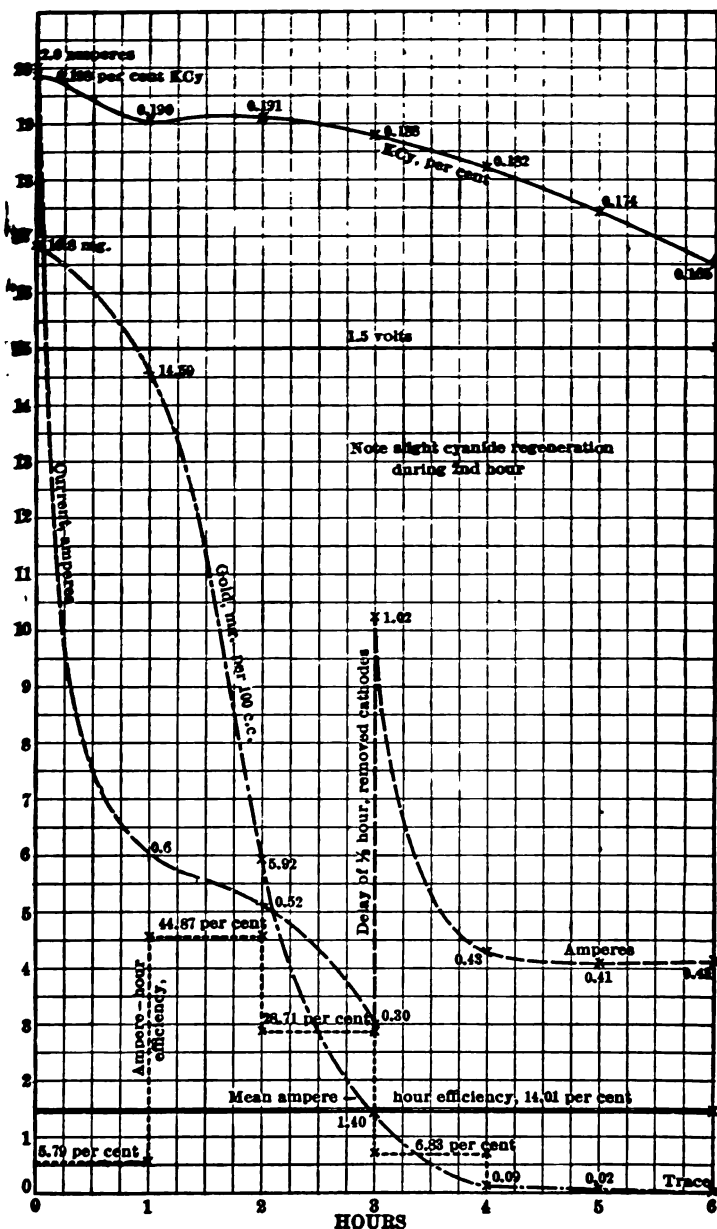


FIGURE 21.—Electrodeposition results with gold cyanide solution. Twenty-two liters of solution, containing 0.198 per cent KCy, 0.1 per cent KHO, and 3.696 grams of Au as KAuCy_2 , taken for test. Seventy 16-mesh wire-cloth cathodes; estimated area, both sides, 2 to 10 square feet. Rate of flow, 8 liters per minute; velocity through open box, 46 inches per minute; through cathodes, 105 inches. Note slight cyanide regeneration during second hour.

ber of important conclusions may be drawn from this experiment (see fig. 21).

First, note the low efficiency during the first hour. The cause of this low efficiency is that between the experiments, which were dis-

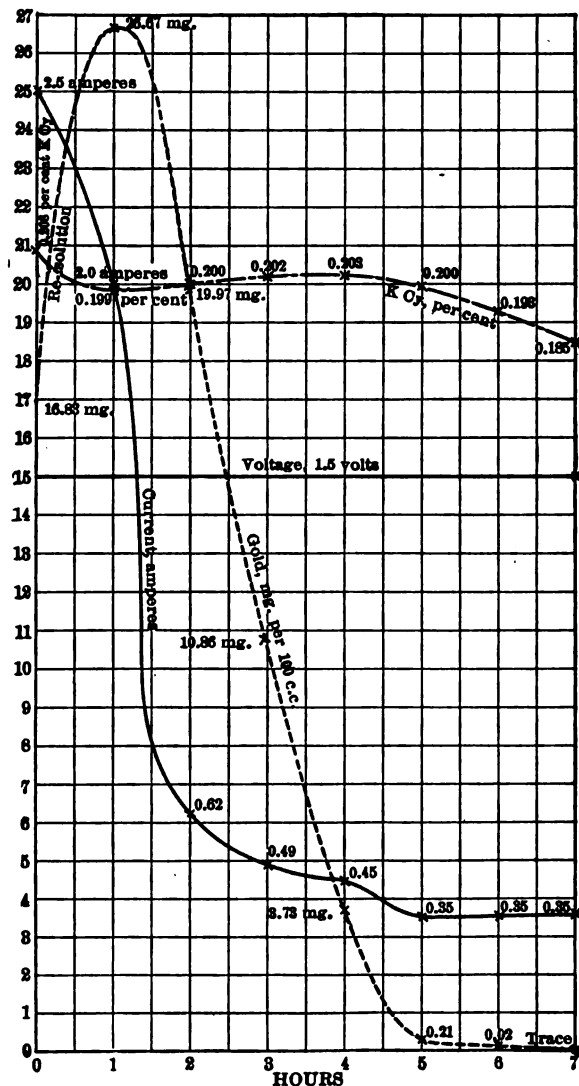


FIGURE 22.—Gold deposition results showing effect of local action on iron-wire cathodes. Eight carbon comb anodes; 70 16-mesh cathodes; estimated surface, between 2 and 10 square feet. Twenty-two liters of solution, containing 0.208 per cent KCy, and 16.83 mg. Au per 100 c. c. Rate of flow, 8 liters per minute; velocity, 46 inches per minute through open box and 105 through cathodes.

continuous, the iron-wire cathodes had rusted, and a large part of the current in the first hour was consumed in reducing the oxide. The

serious nature of this trouble is shown more clearly in later experiments.

Second, the high ampere-hour efficiency in the second hour (44 per cent) would have been still higher if the cathodes had been entirely clean the first hour. The ampere-hour efficiency for the entire six hours, 14.01 per cent, was remarkably high.

The extraction was good. In five hours the gold value of the solution was reduced to 12 cents per ton and in six hours to less than 6 cents. The precipitation is, however, much less rapid than with silver. The rate would have been increased by a higher voltage but at the cost of the ampere-hour efficiency.

A slight regeneration of cyanide during the second hour, when the gold precipitation was greatest, was noted.

THE EFFECT OF LOCAL ACTION ON IRON-WIRE CATHODES.

Attention has already been called to the local action that takes place in intermittent silver precipitation. With gold it is more marked. The serious nature of this difficulty is illustrated by the following experiment: The gold-coated cathodes were drained and allowed to dry over night. They were not dried by heat, as the unequal expansion of gold and iron might cause the coat to scale. However, local action resulted which oxidized the iron with disastrous results. For the first hour, gold dissolved in spite of the current, showing that the coating of gold had been undercut by the rust, thus insulating it from the iron cathode, and allowing it to dissolve. The second hour still shows the bad effect of the rust, although the deposition was fair. The details and results of the experiment (see fig. 22) which illustrates this are as follows:

There were employed eight new carbon anodes. The cathodes were the 14 bunches of fine 16-mesh wire-gauze screens, which had been partly coated with gold from the previous run. The total volume of the solution at the start was 22 liters; it contained 0.208 per cent KCy, 168.3 milligrams gold per liter, and 0.1 per cent KHO. The flow was 8 liters per minute, or 480 liters per hour. The total cathode area was between 1.57 and 7.85 square feet. The area of the composite wire cathodes is hard to calculate. The minimum area would be that of the section of the cloth, 0.112 square feet (counting both faces) for each of the 14 groups, or 1.57 square feet. The maximum would be 5 times 1.57, or 7.85 square feet. In time the entire cloth becomes covered with metal, but not all at once. The true mean would probably be about 4 square feet, a little below the average of 4.71 square feet. The ampere-hour efficiency in this experiment is shown in the following table:

Data showing ampere-hour efficiency in experiment.

Hour.	Gold, mg. per liter.	Difference.	Number of liters treated.	Gold precipitation, grams.	Average ampere-hours.	Theoretical gold, grams.	Ampere-hour efficiency, per cent.
0	168.3						
1	266.7	-98.4	21.79	-2.1442	2.100	15.434	Negative.
2	190.7	+67.0	21.68	+1.4525	1.570	11.540	12.58
3	108.6	+91.1	21.57	+1.9650	.526	3.866	50.81
4	37.3	+71.3	21.46	+1.5300	.478	3.513	43.55
5	2.1	+85.2	21.35	+ .7515	.406	2.984	25.18
6	.2	+ 1.9	21.24	+ .0404	.350	2.572	1.57
7	Trace.	+ .2	21.13	+ .0042	.350	2.572	.16
				+3.5994		42.481	

During the first hour the ampere-hour efficiency was negative, as nearly two-thirds of the gold already precipitated was redissolved; but in the next hour the current had begun to cure the evil, and 12.58 per cent of the current was utilized. During the next hour the efficiency had risen to 50.81 per cent, slowly falling to a fraction of 1 per cent. Besides the dissolved gold the new gold, amounting to 3.6842 grams, was practically all precipitated. However, considering the net gold only, the efficiency is high. Dividing 3.5994 by 42.481 (the weight of gold that the current should have precipitated) gives for the whole period 8.47 per cent, which is a good result in spite of the poor start.

To be sure that the carbon anodes had not prevented the solution (containing 0.185 per cent KCy) from dissolving gold, 100 c. c. of the tailing solution was rotated for half an hour in a $\frac{1}{2}$ -liter flask filled with air to aerate it, and then was rotated with a gold strip in it for one hour. The quantity of gold thus dissolved was 2.47 mg. A parallel experiment with pure KCy (0.185 per cent) solution gave 2.41 mg. Hence the carbon anodes had not prevented solution of gold.

The same wire-cloth cathodes, 14 groups of five, from the above test with gold still on them were again treated with practically the same results. (See figure 23). Eight of the hard-carbon anodes were used. The cathode area was between 1.57 and 7.85 square feet. The rate of flow was 8 liters per minute. The ampere-hour efficiency under the above conditions is shown in the following table:

Data showing ampere-hour efficiency of experiment.

Hour.	Gold, mg. per liter.		Number of liters treated.	Gold precipitated, grams.	Average ampere-hours.	Theoretical gold, grams.	Ampere-hour efficiency, per cent.
	At start,	Difference.					
0	168.3						
1	270.4	-101.1 (?)	21.79	-2.2080 (?)	0.568	4.175	Negative.
2	218.9	+ 51.5	21.68	+1.1165	.410	3.017	37.01
3	165.5	+ 58.4	21.57	+1.1518	.410	3.017	38.18
4	94.0	+ 71.5	21.46	+1.6248	.430	3.161	48.24
5	29.3	+ 64.7	21.35	+1.3812	.434	3.190	43.30
6	2.0	+ 27.3	21.24	+ .5798	.382	2.807	20.66
7	.2	+ 1.8	21.13	+ .0390	.345	2.536	1.50

The net amount of gold precipitated was 3.5891 grams, whereas the current should have precipitated 21.903 grams. Therefore, the total ampere-hour efficiency was 16.39 per cent, and in spite of the poor

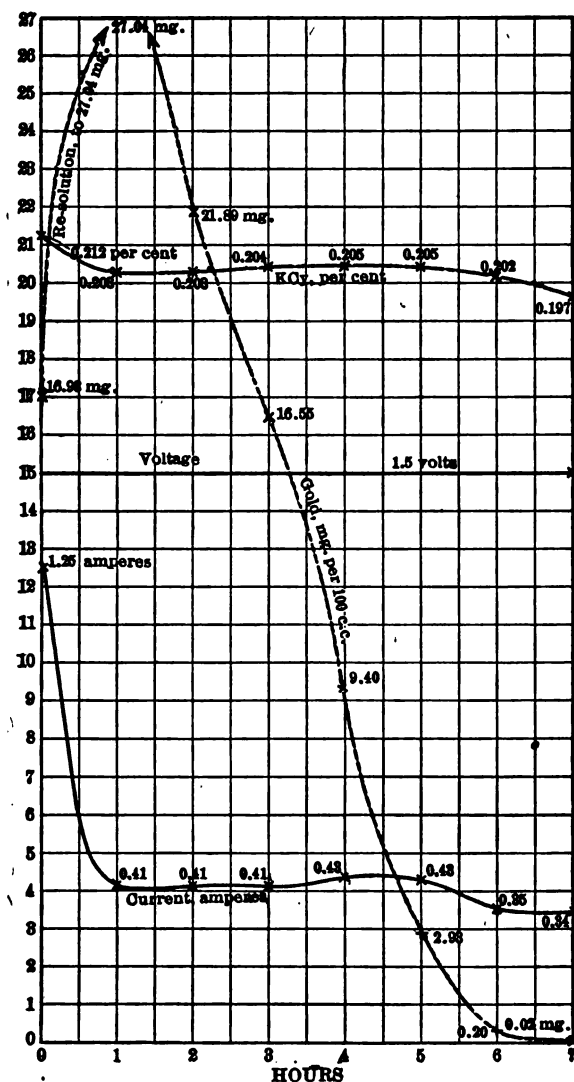


FIGURE 23.—Electrodeposition results showing re-solution of gold due to rusting of cathodes. Eight "Electra" carbon comb anodes. Seventy 16-mesh wire-gauze cathodes, in 14 groups of 5 each; estimated total surface area, between 2 and 10 square feet. Solution, 22 liters, contained 0.212 per cent KCy, 0.1 per cent KHO, and 16.93 mg. Au per 100 c. c. Rate of flow, 8 liters per minute; velocity through open box, 46 inches per minute; through cathodes, 105. Note fall of cyanide during solution of gold and slight rise during fall of gold.

start was decidedly satisfactory for the whole period. The current was rather low because the solution was a new one used for the first

time, and did not contain so many dissolved salts; the current was relatively better after a while because the contacts were better. The fall of the cyanide during the solution of the gold and the slight rise during its rapid precipitation should be noted. The rise was less than the fall, owing to continuous oxidation.

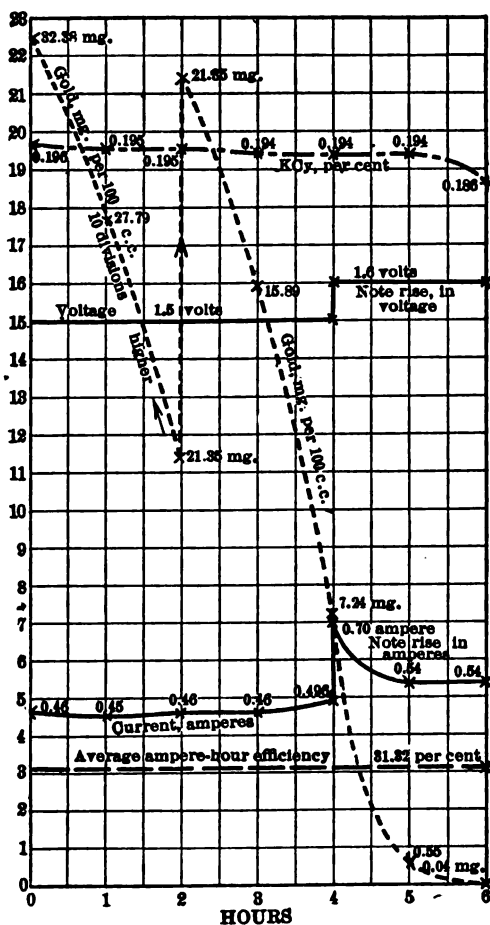


FIGURE 24.—Electrodeposition results with rich gold solution. Solution, 21.68 liters, containing 32.48 mg. Au per 100 c. c. Six carbon comb anodes; seventy (14 groups of 5) 16-mesh wire-cloth cathodes; total estimated surface area, between 2 and 10 square feet. Rate of flow, 8 liters per minute or 480 per hour; velocity through open box, 46 inches per minute; through cathodes, 105.

The next experiment was made with 14 bunches of five cathodes of 16-mesh wire cloth. The total area of these was estimated to be between 1.57 to 7.85 square feet. They were gold coated from previous use. Six carbon anodes were used. The solution contained 0.205 per cent KCy and 0.1 per cent KHO. The flow was 8 liters per minute. The solution at the start contained 16.92 mg. gold per liter,

but owing to bad contacts, the gold dissolved, so that the content in the solution increased to 32.38 mg. The ampere-hour efficiency under these conditions (see also fig. 24) is shown in the following table

Data showing ampere-hour efficiency in experiment.

Hour.	Gold, mg. per liter.		Number of liters treated.	Gold precipitated, grams.	Average ampere-hours.	Theoretical gold, grams.	Ampere-hour efficiency, per cent.
	At start.	Difference.					
0	323.8						
1	277.9	45.9	21.68	0.9061	0.45	3.307	30.09
2	213.5	64.4	21.57	1.3990	.46	3.332	41.07
3	158.9	54.6	21.46	1.1717	.46	3.332	34.65
4	72.4	86.5	21.35	1.8467	.496	3.645	50.63
5	5.5	66.9	21.24	1.4209	.005	4.447	31.95
6	0.4	5.1	21.13	0.1078	.540	3.999	2.72

The average efficiency for the whole period is thus shown to be 31.32 per cent, a result which certainly is very satisfactory.

DEPOSITION OF GOLD FROM DILUTE SOLUTION ON RUSTED IRON CATHODES.

The solution consisted of approximately 22 liters of 0.047 per cent cyanide, containing 1.010 mg. of gold per 100 c. c. Seventy (14 sets of five) coarse wire cathodes were used, the area being between 1.57 and 7.85 square feet. The rate of flow was 7 liters per minute, or 420 liters per hour. The results of this experiment are graphically shown in figure 25.

The cathodes had been used before and had rusted, with an unknown amount of gold on them. During the first hour, owing to the extent of the rusting, the gold stripped off the cathodes and the content in the solution increased to 2.46 mg. per 100 c. c. As stripping would not occur in continuous practice, the analysis begins with this content of gold in the solution. At the close of the experiment all the cathodes except two were coated with gold, but the coating was irregular, showing the effect of the rust. Near the surface, where air had access, the coating was thinner than below. The carbon anode at 1.6 volts did not show any signs of corrosion. The ampere-hour efficiency attained in this experiment is as follows:

Data showing ampere-hour efficiency attained.

Hour.	Gold, grams per liter.		Number of liters treated.	Gold precipitated, grams.	Average ampere-hours.	Theoretical gold, grams.	Ampere-hour efficiency, per cent.
	At Start.	Difference.					
0	0.0246						
1	.0234	0.0012	21.68	0.0260	0.52	3.834	0.68
2	.0210	.0024	21.57	.0518	.46	3.381	1.53
3	.0075	.0135	21.46	.2900	.36	2.646	10.96
4	.0051	.0024	21.35	.0512	.34	2.499	2.06
5	.0023	.0028	21.24	.0695	.32	2.352	2.53

This table shows the detrimental effect of rust on iron-wire cathodes. The gold that had been previously deposited on the cathodes dissolved in spite of the current. It is possible that oxide of iron had formed under the gold and insulated it from the iron, thus enabling the gold to redissolve. The detrimental effect of the rust continued during the next hour and the ampere-hour efficiency was only 0.68 per cent. In the next hour it had risen to 1.53 per cent, and in the next hour to 10.96 per cent. The current, then, is capable of curing the evil, and for this purpose I have devised what I call the "hospital cell," mentioned on page 113.

A test which further shows the effect of rust upon cathodes is the following: Seventy (14 sets of five) gold-coated rusted iron-wire cathodes were used in a solution containing about 1 mg. gold per 100 c. c., or \$6.03 a ton. The cathode surface was between 1.57 and 7.85 square feet. The flow was 7 liters per minute. The experiment was begun with six perforated platinum anodes. The pressure was 2.5 volts. The current at first was 1.33 amperes, falling in four hours to 0.91 ampere. The gold on the rusted iron wires dissolved in spite of the current. The solution was then made up to 22 liters, when it contained 4.12 mg. gold per 100 c. c. and 0.42 per cent KCy. When six perforated and peroxidized-lead anodes were used the voltage re-

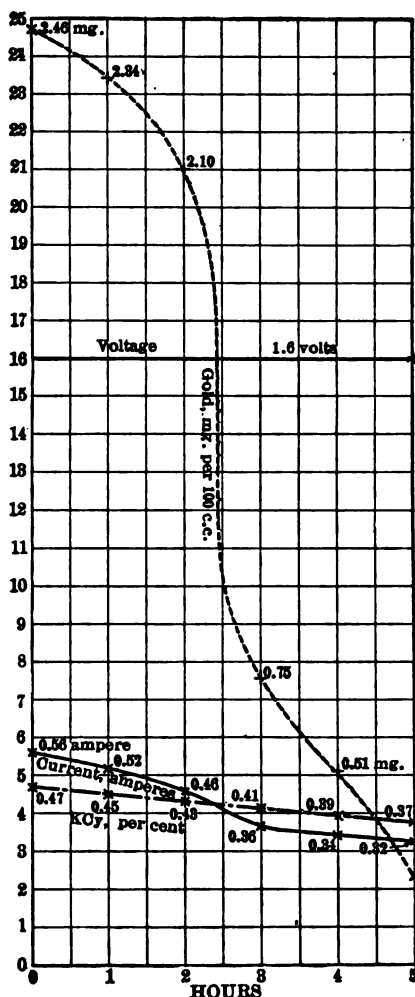


FIGURE 25.—Electrodeposition results with dilute gold solution on rusted iron-wire cathodes. Solution, 21.68 liters, contained 0.047 per cent KCy, 0.1 per cent KHO, and 2.46 mg. Au per 100 c. c. Seventy (14 sets of five) 16-mesh wire-cloth cathodes; estimated surface area, between 2 and 10 square feet. Rate of flow, 7 liters per minute, or 420 per hour; velocity through open box, 41 inches per minute; through cathodes, 91. No rise in cyanide was shown.

maintained unchanged, but immediately the current rose to 3.65 amperes. The results are graphically shown in figure 26. The current efficiency was as follows:

Data showing ampere-hour efficiency in test.

Hour.	Gold, grams per liter.		Number of cells treated.	Gold precipitated, grams.	Average ampere-hours.	Theoretical gold, grams.	Ampere-hour efficiency, per cent.
	At start.	Difference.					
0	41.2						
1	2.5	38.7	22.00	0.55140	1.35	22.588	2.77
2	4.5	2.9	21.40	0.54573	1.39	28.260	0.17
3	Trace.	4.5	21.75	0.50289	1.55	28.088	0.04

The precipitation is at the rate of about 176 tons per day in a 1-ton box, much better than that obtained by Siemens & Halske. Moreover, this result is evidently all that could be desired, but it was accomplished at the expense of the ampere-hour efficiency. Of course good precipitation is vital, and is more important than electrical efficiency. This would have been higher, except for the rusted condition of the cathodes. The great importance of overcoming the difficulty from rusty cathodes is evident, and will be specially considered later.

Most of these experiments with gold solutions were conducted at too low a voltage for rapid and complete precipitation. Low voltages were purposely used to find the lowest limit that would give high electrical efficiency and satisfactory regeneration of cyanide. With the ordinary gold solutions used in mill practice the cyanide regeneration is so small that it is obviously better to run at a higher voltage, at least 2.5 volts, to insure rapid and complete precipitation.

EXAMPLE OF A GOLD CLEAN-UP.

The next problem for consideration is that of recovering the gold deposited upon the iron wire-cloth cathodes. Fourteen "bunches of five" of these cathodes had been coated with about 14.7 grams of gold in the experiments just described.

Six flat, sheet-iron, graphite-coated cathodes were inserted in the box along with the 14 cathodes to be stripped and now serving as anodes. A 0.97 per cent potassium cyanide solution was circulated in the stripping box by means of the centrifugal pump. A "Nungesser" cell was used to supply the electrolytic current. The voltage, which at first was 0.75 volt, decreased in one hour to 0.39, then, as the stripping progressed, gradually rose to 0.69 in six hours. The gold was thus concentrated on both sides of six sheet-iron cathodes. As the film was very thin, however, three of the cathodes were made anodes and the gold was all concentrated on three cathodes.

The Nungesser cell gave at first 0.50 volt and 0.26 ampere. After

being allowed to run 16 hours over night, the cell gave in the morning a voltage of 0.70, and the current had fallen to 0.001 ampere.

The three cathodes were coated on both sides with a beautiful clear yellow coat of metallic gold which could be easily stripped from the graphite-coated iron in a tough coherent film, the gold thus recovered weighing 6.069 grams. The cyanide content was reduced to 0.57 per cent during this deposition.

The solution from the clean-up box contained 329.05 mg. gold per 100 c. c. (one-third per cent), thus the 1,800 c. c. held 5.923 grams. Loosely adhering to the cathodes was some fine gold which weighed 130 mg. Hence there was recovered in sheet metal, by a voltage of less than one volt, 6.069 grams of sheet gold and 0.130 gram of scrap. The amount of gold in solution not precipitated was 5.923 grams, making a total weight of 12.122 grams. Unfortunately in starting the experiment part of the rich solution was lost so that a check was not possible.

Evidently, to recover all the gold a higher voltage, say 1.6 or 2.5 volts, would have been necessary. Complete precipitation and recovery of the gold by electrolysis could be made at any time. This has been done time and time again,

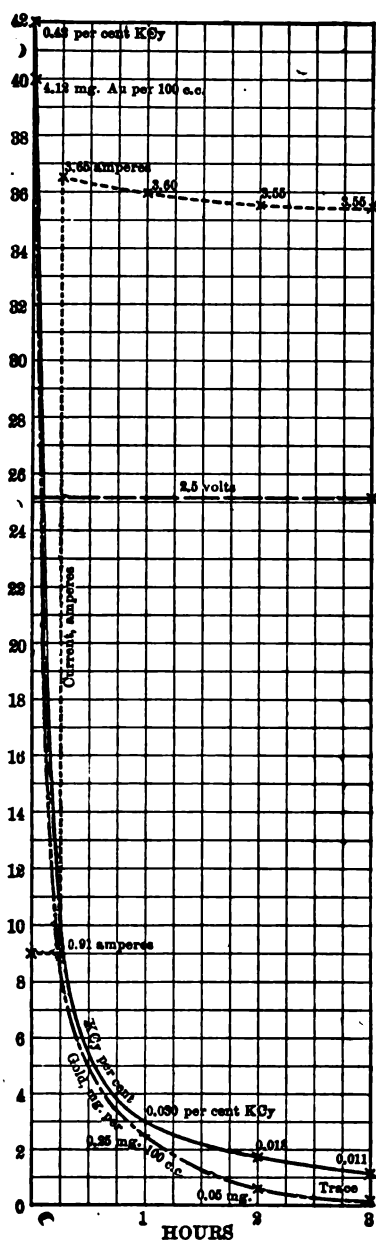


FIGURE 26.—Electrodeposition results showing effect of rust on cathodes. Seventy (14 sets of five) 16-mesh gold-coated rusted wire-cloth cathodes used; estimated surface area, between 2 and 10 square feet. Solution, 22 liters, contained 0.42 per cent K_2Oy , 0.1 per cent KHO , and 4.12 mg. Au per 100 c. c. Rate of flow, 7 liters per minute or 420 liters per hour; velocity through open box, 41 inches per minute; through cathodes, 91. For first quarter hour, 6 platinum anodes used; current was only 0.91 ampere; then 6 perforated peroxidized (PbO_2) lead anodes were used; current rose to 3.65 amperes. Note the better precipitation at higher current, but greater and continuous destruction of cyanide.

so there is no doubt on that point. The sheets of gold adhering to the cathodes obtained here are a complete refutation of the claim of Prof. Neumann that recovery of the gold in this manner is impossible.

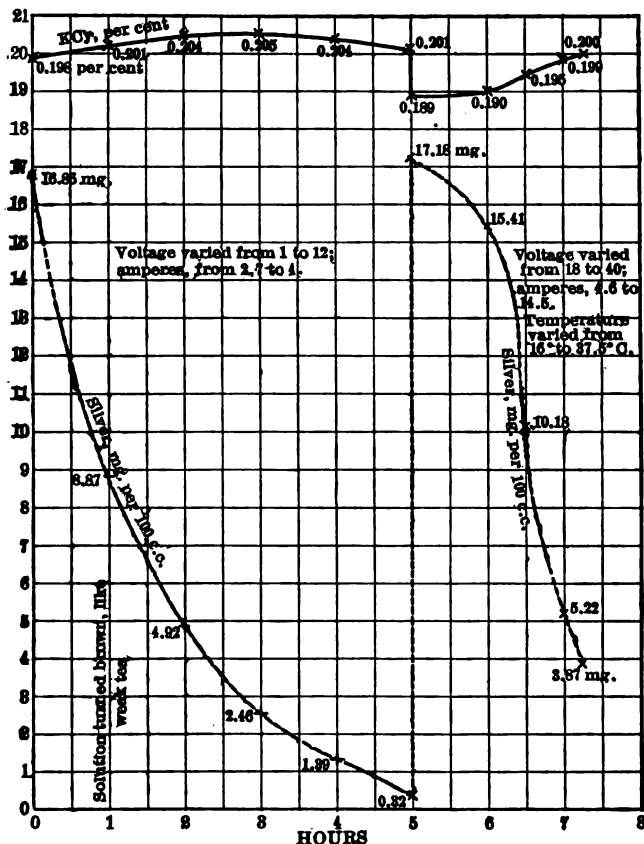


FIGURE 27.—Results of silver electrodeposition with cathodes and anodes horizontal. One perforated sheet-iron anode. One set of five 30-mesh iron wire-cloth cathodes, each 10 by 8.5 cm.; total area of pervious part, 81 square cm.; area when covered with silver was indeterminate. Rate of flow, 11 liters per minute or 660 per hour; velocity through open box, 53 inches per minute; through cathodes, 120.

RECOVERY OF SILVER ON HORIZONTAL PERVIOUS CATHODES.

All the electrodes previously considered were placed vertically in the deposition box. It was now thought wise to see what could be done in silver recovery by using horizontal pervious cathodes, with removable pervious anodes above them. If this arrangement were successful, a clean-up would be unnecessary, for the silver could be scooped up with a shovel. Such a construction is not so favorable for deposition as the previous arrangement, for only one anode

One cathode can be used in each box. An anode can not be placed below the cathode on account of interruptions from the gas free; the area could be increased, however, by placing the shallow cells in cascade one above another. High voltages were used in an

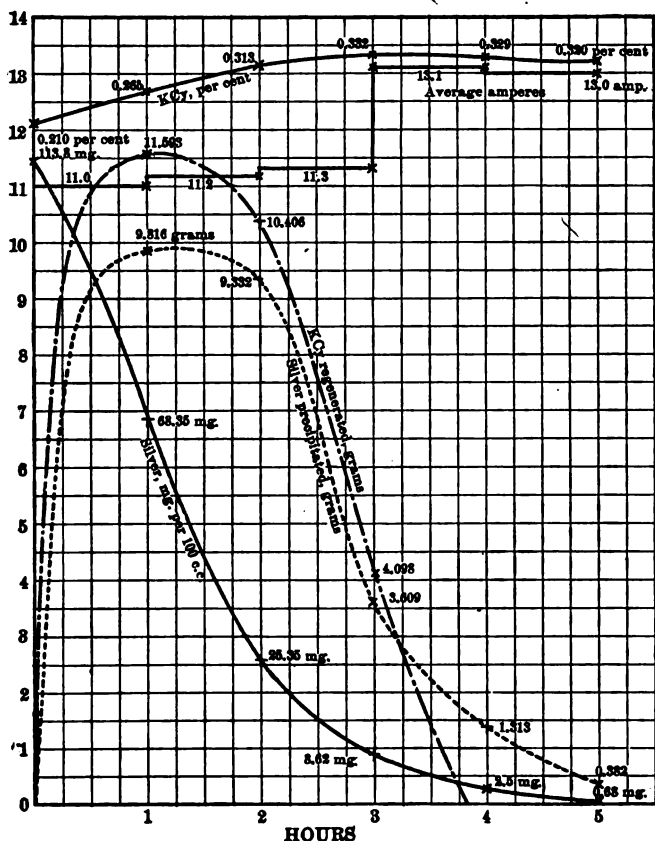


FIGURE 28.—Results of silver electrodeposition with single horizontal electrolytic filter. First 3 hours a perforated platinum plate was used as anode; last 2 hours, 12 turns of No. 18 platinum wire. One set of five 30-mesh iron wire-cloth cathodes, each 10 by 8.5 cm. Rate of flow, 10 to 12 liters per minute; velocity through open box, 53 inches per minute; through cathodes, 120. Voltage, 22 to 50 volts; current, 4.8 to 13.1 amperes, too variable to plot. Room temperature, 16.5° C.; solution rose to 51.5° C. in 5 hours. Note parallelism between weight of silver deposited and weight of cyanide regenerated.

endeavor to make up for the small cathode surface. Very little silver was deposited on the lower wires of the cathode, the up-growing deposit of silver soon formed its own pervious cathode.

I used only one bunch of five sheets of iron-wire cloth placed horizontally, to serve as the cathode, and a perforated platinum sheet as the anode. The solution was circulated by a centrifugal pump so that it passed continuously down through the anode and then through the

cathode. The cathode was 10 by 8.5 cm. in size, only 81 sq. cm. of which was pervious. The voltage, which varied, began at about 3 and finally was raised to 40 volts. The rate of flow was 11 liters per minute, or 660 liters per hour. The results are shown in figure 27. At the end of the second hour the solution began to have a slight brownish cast, which gradually increased, till at last it was dark reddish brown, about like black-tea infusion. Its temperature had risen to 37.5° C. The room temperature was 20° C. At the end of the fifth hour 3.76 grams of Ag as KAgCy₂ was added and 1.3 liters of water to make the total volume up to 22 liters. The silver was deposited as a loose, gray sponge on the wire gauze, which was coated only on the top.

Even if boxes were separately arranged in cascade one over another, it is probable that sufficient cathode area to render the method practicable could not be obtained. Such high voltages as were used are, of course, out of the question, but the clean-up would be simple (the sponge was a beautiful, feltlike network, pervious to the solution). All that would be necessary in practice would be to remove the silver with a shovel.

EXPERIMENT WITH A HORIZONTAL ELECTROLYTIC FILTER.

An experiment was made with a horizontal electrolytic filter. In this apparatus the anode, of perforated platinum, was at the top. After three hours, 12 turns of No. 18 platinum wire were used. The cathodes were of wire cloth such as had been used previously, and were each 10 by 8.5 cm. in dimension. The solution, 22 liters, contained 0.211 per cent KCy and 0.1 per cent KHO. The flow was at the rate of 10 to 12 liters per minute. The results are shown in figure 28.

At the end of the second hour the experiment was temporarily stopped, and the cathodes were removed during the noon hour at that time. At the end of the third hour the perforated platinum sheet was removed and replaced with a platinum wire anode. This wire anode allowed a better escape of the gas from the anode and gave a stronger current at a lower voltage. The ampere-hour efficiency is shown in the following table:

Data showing ampere-hour efficiency in experiment with horizontal filter.

Hour.	Silver content, mg. per liter.		Number of liters treated.	Silver precipitated, grams.	Ampere-hours.	Theoretical silver, grams.	Ampere-hour efficiency.
	At start.	Difference.					
0	1138.4	-----	-----	-----	-----	-----	-----
1	683.5	454.9	21.79	9.816	11.0	44.270	22.17
2	253.5	430.0	21.68	9.332	11.2	45.080	20.70
3	86.2	167.3	21.57	3.609	11.3	45.480	7.94
4	25.0	61.2	21.46	1.313	13.1	52.724	2.47
5	6.8	18.2	21.35	0.382	13.0	52.324	0.78

The ampere-hour efficiency was high notwithstanding the wastefully high voltage used; it averaged 10.19 per cent for the entire period. Such high efficiency would have been impossible except for the rapid circulation. The metal came down as a beautiful white, porous layer of spongy silver, $\frac{1}{4}$ inch thick, of such quality as to permit it to be scooped up with a shovel. This might be a convenient modification of the clean-up box, but some material for the "cathode-anodes" would have to be used that would not be corroded after the current were stopped—excelsior charcoal, for instance.

REGENERATION OF CYANIDE.

During the first three hours there was a remarkable regeneration of cyanide, as is shown in the following table:

Data showing regeneration of cyanide.

Hour.	KCy content.	Increase.	Volume treated.	KCy regenerated.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Liters.</i>	<i>Grams.</i>
0.....	0.210	.....	.....	.....
1.....	.265	+0.055	21.79	+11.593
2.....	.313	+ .048	21.68	+10.406
3.....	.332	+ .019	21.57	+ 4.098
4.....	.329	a- .003	21.46	a- .644
5.....	.320	a- .009	21.35	a- 1.922

a Loss.

The total number of grams regenerated in three hours is seen to have been 26.097. The ratio of cyanide regenerated to the silver precipitated was as follows:

First hour.	$\frac{\text{Weight of KCy} = 11.593}{\text{Weight of Ag.} = 9.816} = 1.181.$
Second hour.	$\frac{10.406}{9.332} = 1.121.$
Third hour.	$\frac{4.098}{3.609} = 1.135.$

Suppose that for each gram-atom of silver precipitated (molecular weight, 108), two gram-molecules of KCy (molecular weight, 130) were regenerated; then for each gram of silver 1.2037 grams of KCy would be regenerated at the cathode. In this experiment conditions were more favorable for reduction at the cathode than for oxidation at the anode, and the highest ratio attained was very nearly, but not quite, the maximum that would have been possible had there been no oxidation at the anode. It would seem, then, either that the great current density at the anode tended to prevent oxidation, or that the lesser density at the cathode favored reduction of the cyanate formed at the anode. Probably both tendencies acted together to produce this favorable result.

ANODES.

"Oh, for an anode!" There is no one who has done much electrolytic work who has not uttered this exclamation from the bottom of his soul.

SOLUBLE ANODES.

The idea of using soluble anodes so as to avail one's self of the solution energy of the soluble anode is at first thought a perfectly natural one, but on working over the field, only two soluble metals are available, zinc and aluminum. Logically, iron may be considered as a soluble anode; but for convenience, anodes of iron are discussed under the heading "Insoluble Anodes" (pp. 98 to 108).

ZINC AND ALUMINUM.

If commercial zinc is used as an anode, the gold and the silver are precipitated on the anode by local action, even more than on the cathode. Hence both anode and cathode have to be cleaned. To prevent local action on the anode, the use of amalgamated zinc plate for anodes has been proposed by Croasdale.* But unless the anodes are made very thick and heavy and expensive, they become brittle when amalgamated and fall to pieces. The large area necessary in treating dilute gold solutions is hard to obtain. The same objections apply with even greater force to the use of soluble aluminum anodes. Difficulties of ore leaching, caused from the gelatinous hydrate of aluminum, are further complications, and quicksilver rots aluminum plates even more fatally than zinc.

I think it is safe to take the position that if zinc or aluminum are to be used to precipitate gold or silver from cyanide solutions they should be used alone and without external electricity, as the combination of these metals with applied electric energy does not seem to be a happy one.

INSOLUBLE ANODES.

Insoluble anodes, of course, add no energy to the bath, and offer an increased resistance to the current owing to polarization effects. Nevertheless in treating ore solutions such anodes would be better than soluble ones if they really could be obtained absolutely insoluble and permanent in daily use.

PLATINUM.

Platinum, if it were cheap, would solve most of the problems; but except for experimental work and for certain rare uses its high cost puts it entirely out of the question.

* Croasdale, Stuart, Electrolytic precipitation of gold from cyanide solutions: *Eng. and Min. Jour.*, Dec. 12, 1896, vol. 62, pp. 557-558.

HARD CARBON.

Hard electric-light carbon serves admirably in cyanide solutions when the voltage is kept below that at which water is decomposed. But this point is so low (1.48 volts) that it is below the voltage necessary to use in practice. At higher voltages the carbon is slowly acted upon, and the solution becomes colored like weak tea. I have found, however, by repeated experiments that even when darkly colored such cyanide solution, when aerated, will dissolve gold as freely as fresh cyanide solution of equal strength. This form of carbon resists the chlorides very well but soon succumbs to alkaline sulphates, which are sure to be present in cyanide solutions after treating sulphide ores and must be reckoned with. I have tried to increase the resistance of this form of carbon by boiling for several days in vaseline or paraffin the anodes made of it, in order to confine corrosive action to the surface, but these efforts have been without success.

ACHESON GRAPHITE.

Graphite anodes, as produced by Acheson, of Niagara Falls, in the electric furnace, are a great improvement on the ordinary hard carbon. The substance is a better conductor than ordinary carbon and is much more resistant, but in practice it, too, fails when used with solutions containing soluble sulphates. As already mentioned in the experience with Acheson graphite anodes in the Oliver process, at the North Star mine, as long as the process was confined to the treatment of solutions coming from sands that contained very little sulphate, the anodes stood up very well, but as soon as solutions coming from the concentrated sulphides were treated, the abundant sulphates soon reached the weak points of the anodes and they disintegrated finally into a soft black mud. This failure was one of the causes that led to the abandonment of the entire process. The ease with which the Acheson graphite can be machined in a lathe and built up into many forms is a great advantage. I have used it in my experiments in the form of "comb anodes." These are made by screwing four $\frac{3}{8}$ -inch graphite rods, so as to project $4\frac{1}{2}$ inches, into the rectangular block or base bar, also of graphite. Such anodes are rather brittle and have to be handled carefully, but if sulphate solutions are avoided they will last for years. There is never any doubt as to the security of the connections. I usually solder a copper wire to a brass ring, which tightly fits around one of the projecting rods; then the anode requires no further attention, except to avoid dropping it. Enough has been said to show that the Acheson graphite anode can not be said to solve the entire problem.

PEROXIDIZED-LEAD ANODES.

The discovery by Andreoli that peroxidized-lead anodes could be used in cyanide solutions has been of great value to the art. It does not seem to be a matter of indifference how these anodes are prepared. It would seem as if those prepared either as is done by Mr. Butters—namely, by scratching the surface with a stiff brush and then making them anodes in a 1 per cent solution of permanganate of potassium for at least one hour, employing a current density of 1 ampere per square foot of anode—or else by making them first for a short time cathodes and then anodes in a caustic potash solution containing peroxide of lead, give better results with cyanides than those peroxidized in sulphuric acid. However, it is not absolutely certain which is the better way, as enough work has not been done on the subject.

Well prepared, these anodes last about a year. Sooner or later they begin to show white, downy, fungus-like growths that form usually in vertical streaks, which extend up and down the plate. If these growths are cleaned away, naked lead is seen to have been exposed to corrosion. "Local action" has started and deep depressions are formed in the plate, which soon disintegrates. Prof. Kerns says that these white formations are composed of the hydrate of lead. That they often contain lead cyanide I have proved by the following experiment.

Some of the white formation was washed by decantation till the washings failed to give any reaction for cyanide of potassium. The residue was then placed in a flask, acidified with sulphuric acid, and air was blown through the mixture and allowed to bubble through a 1 per cent solution of caustic potash. In a short time a distinct reaction was obtainable for cyanide in the alkaline solution.

It would appear that the substance is a varying mixture of hydrate, carbonate, and cyanide of lead. In time such a growth sometimes becomes slightly peroxidized on the surface, but once it has started, eats like a cancer through the plate. Prof. Kearns suggests that the cause of these growths starting is the porosity of the peroxide film. This is most likely; but I have seen growths start on thick coatings where the occurrence of pores was unlikely. Seemingly a frequent cause may be the cracking of the rather brittle oxide when the plastic lead beneath it is bent. The films on these long lead strips may be easily cracked by bending of the sheets as they hang loose in the bath, and particularly by their being handled.

Another possibility is that under certain, but as yet unknown conditions of current density (accidental short circuits, perhaps) and temperature, the anion AuCy_2 or its components AuCy and Cy may act as reducing agents on the PbO_2 , thus exposing naked lead to the

action of the current. A similar reaction was encountered when I once tried to dry out a mixture of PbO_2 and glycerin on the steam bath. The mixture was decomposed with almost explosive violence and abundant minute shots of metallic lead were reduced from the mixture.

The flat shape of the ordinary sheet anode renders it peculiarly sensitive to a rupture of the protecting surface by bending. In order to meet this difficulty I have devised an improved anode (U. S. patent No. 883170, Mar. 31, 1908).

For this purpose I construct a frame of wood, shown in vertical longitudinal section at *A*, and in vertical cross section at *B*, in figure 29. If the wooden frame, *a*, is made large it should be strengthened by horizontal cross bars *b*. Strips of lead wire, *c*, one-eighth to one-fourth of an inch thick, and of cylindrical form are drawn through suitable holes bored in the horizontal bars of the frame, spaced one-half to one inch or more, thus stretching the lead wires, like the wires of a harp, alternately up and down through the frame. The wires are connected on the top by a lead bus bar, *d*, large enough to carry the total electric current, the individual wires being so proportioned as to carry their part of the electric current, which they must do without overheating. I prefer to protect the wood from the solution by painting it with the so-called "P & B" paraffin paint or some other similar substance. The bottoms of the lead wires are kept from touching the bottom of the box by placing them in a groove in the lower horizontal cross bar. Where the wires pass over the lead bus bar at the top they are secured to the bus bar, preferably by the process of lead burning rather than soldering, although soldering may be used if necessary. The end of the bus bar is connected at *e* with a copper wire, which connects with the main bus bar or the conductor introducing the positive current. After the anodes are thus constructed, the lead wires are prepared as follows:

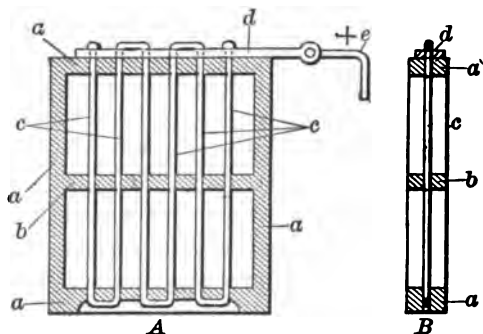


FIGURE 29.—Anode frame designed to prevent bending of metal. *A*, vertical longitudinal section; *B*, vertical cross section. *a*, Wooden frame; *b*, cross bars; *c*, lead wire; *d*, lead bus bar; *e*, copper wire connection to bus bar.

In order to get a clean metallic surface on the outside of the wires free from all insulating substances, I connect the wire with

the negative pole of a suitable source of electrical energy, making the lead wires cathodes for a short time in a solution of plumbate of soda. Any oxide or carbonate or hydrate that may have been formed on the outside of the lead wires becomes thus reduced to the metallic state, and an even surface is produced on the outside of the wire of lead. Without waiting for the film to oxidize in any way, the electric current is immediately reversed and the lead wires are made anodes in the same solution and are kept there until a firm, adherent, dark chocolate brown coating of peroxide of lead forms over every portion of the wire exposed to the action of the current. When this coating is of sufficient thickness to protect the wire, it forms a cylindrical film or tube of firmly adherent peroxide of lead. The anodes are then ready to be inserted into the bath of copper sulphate, cyanide of gold or of silver, or other solution to be treated, to act as pervious peroxidized-lead anodes. These peroxide-coated lead wires may also be replaced by solid rods of lead peroxide similarly arranged in a suitable frame.

Solid rods of peroxide of lead are not so good conductors as those with a lead core, hence they have to be made larger in section to carry the same current. They are, however, more durable. The wooden frame serves to protect the anode rods both from deformation and from destruction by short circuits. The tube-like coating of PbO_2 upon the lead wires is less likely to scale than the coating on flat moving sheets. With sheets the slightest deformation is likely to cause the coating to scale. The wire anodes thus described expose less surface to the bath than the flat anodes. They thus give a lower oxidizing effect, an advantage which is highly desirable in treating cyanide solutions.

It is hard to obtain data on the conductivity of lead peroxide. Landolt and Börnstein* give the following for "hydrated lead peroxide":

Conductivity of "hydrated-lead peroxide."

	Conductivity, per c. c.	Resistance, ohms per c. c.
	0. 163	6. 13 (Shields)
	4. 68	0. 214 (Weyde)
With 1.5 per cent H_2O -----	335. 00	0. 00298 (Ferchland)
Pressed powder-----	0. 435	2. 3 (Sheintz)

The conductivity of lead, at ordinary temperatures is given at 1.99×10^4 to 5.35×10^4 per cubic centimeter, or the resistance varies from 5.02×10^{-5} to 1.87×10^{-5} ohms.

SHEET-IRON ANODES. .

As already remarked, logically sheet-iron anodes should be classified under "Soluble anodes," but it is more convenient to discuss

* Landolt, H. H., Landolt-Börnstein *Physikalisch-chemische Tabellen*, 3d ed., 1905, p. 723.

them here. Sheet-iron anodes were used first by Siemens. It is well known that with a weak current the iron combines with the cyanide and cyanogen to form potassium ferrocyanide, which forms, with various iron oxides, Prussian blue and other compounds. If the current is of a certain density a protecting oxide coating forms on the anode, from the oxygen set free there, and the anode lasts very well. But if there are chlorides in the solution, the iron salt of this acid forms at the anodes and is secondarily decomposed by the alkaline solution, forming at last hard, warty crusts of ferric hydrate several inches thick. Sulphates seem to be nearly as harmless, but chlorides which are harmless to carbon are fatal to iron anodes.

These crusts increase the electrical resistance. Moreover, they contain considerable cyanide of gold, which has traveled to the anode and become entangled, making an objectionable residue that is hard to treat. Also, the cost of the quantity of iron thus destroyed, amounting in large-scale work to many tons, is considerable.

"PASSIVE IRON" ANODES.

The well-known but elusive substance known as "passini iron" was first suggested as an anode in cyanide solutions by Hittorf,^a and it has been again proposed by Kern^b as a cure for the trouble above described. For the purpose he treated the metal as follows:

The iron anodes were rendered passive by first "removing grease by digesting them in hot caustic soda solution, rinsing in water, then putting them into a dilute solution of mixed sulphuric and hydrochloric acids in order to remove all oxide, washing with clean water, thoroughly drying, and finally placing them in concentrated nitric acid and allowing them to remain for about two hours. By this treatment the iron plates were coated with a film of magnetic oxide (Fe_3O_4). On removing the plates from the concentrated nitric acid they were immediately washed with clean water and thoroughly dried to prevent the formation of ferric oxide (Fe_2O_3)." The manner of drying is not mentioned. It is an important omission in such a delicate operation. Kern expresses great satisfaction with the "passive iron anodes," but the experiments he describes only lasted a couple of hours, and he does not seem to have tried the effect of NaCl and Na_2SO_4 . Long experience shows that the conditions governing "passive iron" are too uncertain and too little understood to pin much faith to anodes so constructed. I have been unable to find any of the many directions for producing them to give a result that would make a permanent anode that would stand up with

^a Hittorf, W., *Über passivität der Metalle*: *Ztschr. Phys. Chemie*, Bd. 34, 1900, p. 395.

^b Kern, E. F., *Electrolysis of cyanide solutions*: *Trans. Am. Electrochem. Soc.*, vol. 24, 1913, pp. 241-270.

cyanide solutions containing chlorides under tensions of three or four volts and not break down. Ferric hydrate and Prussian blue soon form the usual crusts and the anode falls utterly.

If some such method could be perfected it would be of the greatest practical utility, not only in electrolysis, but in all the other industrial uses of iron. The investigation of "passive iron" has occupied the attention of many able men for years, but there is no general agreement as to the cause of the phenomena. I use the plural advisedly. If the cause were once surely settled some practical measures would almost certainly result. But "where doctors disagree who shall decide?" The patient usually succumbs, and that is what happens to the "passive iron" anode when it is put to practical use.

An interesting symposium on the passivity of metals was held November 22, 1904, in London by the Faraday Society.* The discussion, which is well worth close study, shows that the phenomena are too varied to be covered by a single theory. The three important theories that are held are the following:

1. The oxide film theory, proposed by Faraday.[†]

2. The valency theory of Fiksdalsten and Krüger,[‡] and of Müller.[§] This assumes that the metal is in an electric condition which alters its valency and renders it more "noble." Fiksdalsten assumes that in the case of iron, both bivalent and trivalent atoms are present, and the passivity consists in either removing the bivalent atoms from the surface or changing them into the trivalent kind. Eintlör,^{||} disagrees with Faraday in the assumption, and although he seems to incline to some such view, does not name himself.

3. The reaction velocity theory of Le Fèvre, which presupposes two passive conducting reactions, the changing rate of which produces the various effects. There are three or four modifications of his theory which are rather miscellaneous in their refinements and to discuss them in detail would take us too far afield.

As early as July, 1900, I had hopes of inducing "passive iron" anodes. Iron was made "passive" in a mixture of sodium citric and sulphuric acids, and after washing the specimens of iron so treated were made anodes in potassium cyanide to which a little silver nitrate had been added. The anodes were attacked with free formation of

* *Report of the Faraday Society, The Institute of Metals, Trans. Faraday Soc.*, vol. 10, March, 1905, pp. 23-25. Abstracted in *Met. and Chem. Eng.*, vol. 12, December, 1905, p. 679. Eintlör, Michael, on a peculiar voltaic condition of iron. *Philos. Mag.*, vol. 9, 1904, p. 5-6.

† *Transactions, Am. Chem. Soc.*, vol. 24, 1902, p. 114.

‡ *Zeitsch. V. L. der Elektrolyt. der Metalle*, *Zeitsch. Phys. Chem.*, Bd. 48, 1904, p. 17-24.

§ *Zeitsch. V. L. der Elektrolyt. der Metalle*, *Zeitsch. Phys. Chem.*, Bd. 50, 1904, p. 33.

hydrates and other compounds. Iron boiled in paraffin was similarly attacked. Electric-light carbon which had been boiled in paraffin to fill the pores was at eight volts disintegrated on the surface into a sludge.

On July 7, 1900, I conducted an experiment with a 0.5 per cent cyanide solution containing gold and silver as cyanides and 1.5 per cent common salt. For the anode I used a small ornamental cast-iron scroll that had been well coated with a magnetic iron coating by the Bower-Barff process. Four volts gave a current of 0.100 ampere, with a wetted area of about 10 square inches. After $3\frac{1}{2}$ hours the current had risen to 0.250 ampere. Red hydrate of iron, but no Prussian blue, had formed on each of the little spots where the protective covering had scaled off. The main body of the coating did not appear to have been attacked in the least. The scroll has since lain around the laboratory and been exposed to various atmospheric conditions without further change, which goes to show how energetic anodic oxidation is, particularly when assisted by a little salt.

Two days after making the test above described I took a wire nail about one-eighth inch thick and heated it to redness till it acquired a uniform coat of scale. When cold this proved to be a fairly good conductor. I made the nail an anode in a bath of 200 c. c. of 0.5 per cent KCy solution, containing $KAgCy_2$, to which 20 c. c. of a saturated solution of NaCl had been added. The nail was immersed about 3 inches. At 2 volts it permitted the passage of a current of 0.001 to 0.002 ampere, and was very little acted on except at the point. I allowed the current to run over night and found in the morning that it had risen to 0.100 ampere. A large quantity of a greenish-yellow slime had formed and settled out. The nail was half eaten through at the end and near the middle, but otherwise the black magnetic coating was intact. When the slimy hydrates were removed, the part eaten out below the slime was bright and white like silver. Evidently where the coating was intact it protected the iron from attack, but wherever there was a defect in the coating the iron was corroded rapidly, evidently forming a short-circuit couple between the iron and the oxide coating, which had made the corrosion more active on account of the "local action." I have experimented in this direction and have had hopes of working out a method that will give a firm coherent coating of magnetite on cylindrical iron rods, enabling the construction of a grid anode coated with magnetic oxide of iron similar to the grid anode of peroxide of lead.

Evidently in the two tests cited the "passivity" was due to an oxide film, and the explanation suggested by Faraday holds good. Films so formed are not necessarily of Fe_3O_4 , as assumed by Prof. Kern, but seem to be mixtures of FeO and Fe_2O_3 in varying propor-

tions. There is more of the Fe_3O_4 on the outside and more FeO on the inside. The films are usually magnetic. The least defect in the rather brittle coating exposes the interior and corrosion ensues in a way similar to that of iron poorly electroplated with copper. The iron rusts rapidly, even under the copper coating, and scales worse than does the magnetic coating. If the magnetic coating is thick, it chips very easily, but if it is thin it seems to be porous. These defects are recognized by the Bower-Barff concern, which always dips thin light-coated grill work for interiors in melted paraffin to fill the pores in the coating. Whether a durable coating of this oxide can be obtained for anodes subject to bending and warping in handling is open to doubt.

The failure of iron anodes made "passive" in strong nitric acids, or by anodic polarization in alkaline oxidizing agents, may be due also to porosity. The film, or whatever the protecting condition is, appears to be too delicate for practical use. Grave* claims that the pure iron is passive but the presence of hydrogen ions destroys this passivity. The "passive" state created by acid treatments is evidently too unstable to serve as the base of any industrial method in the present state of knowledge, but the importance of the subject warrants further research.

ANODES OF MAGNETITE.

Henry Blackman (U. S. patent 568231, Sept. 22, 1896) claims the use of electrically conductive anodes of iron oxide in a dense impermeable mass. He specifies the use of magnetite or ilmenite cut from a slab of the mineral, which would be a difficult task. He specifies also the agglomeration of grains of these minerals by tar or sugar or by means of suitable fluxes. This, of course, is objectionable as the binder yields and also acts as an insulating agent.

I have tried a pervious mass of loose magnetite grains held in a box with cheesecloth sides, but the mineral in this shape is neither sufficiently pervious to the solution nor of sufficient conductivity.

Heinrich Specketer (U. S. patent 931513, Aug. 7, 1909) claims the use of anodes cast in rods from molten magnetite. He fuses Fe_2O_3 , which changes on melting into Fe_3O_4 with a slight excess of FeO , the latter crystallizing in a different system from the magnetite and causing it to disintegrate. This oxide is removed by adding a small amount of finely pulverized Fe_2O_3 to the melt just before pouring into the molds. The mass solidifies on the outside first and the molten interior can be poured out, leaving a hollow tube which can be electroplated with metal on the inside, to make it a better con-

* Grave, Ernst, Neue Untersuchungen über die Passivität von Metallen: Ztschr. Phys. Chem., Bd. 77, 1911, pp. 513-576.

ductor, or a rod of iron, copper, or nickel can be inserted in the still plastic interior. This patent has been assigned to the Chemische Fabrik Griesheim Electron, of Frankfort, Germany. The firm has undertaken its manufacture.

A part of one of these anodes, broken from a larger part, was sent me by Mr. Haigh, president of the Moore Filter Co. It was formerly used in connection with the Clancy process. The piece is of a uniform, bluish-black color, is about 10 inches long by five-eighths inch in diameter, and is cylindrical. An inch and a half near the top has been electroplated with copper to facilitate making contact. The coating is thin and has partly scaled off.

I have used this specimen as an anode in a 0.2 per cent cyanide solution without sodium chloride and sodium sulphate, with 1 per cent sodium chloride in one experiment, and with 1 per cent sodium sulphate in another, employing 4 volts, without the slightest apparent formation of either ferrous hydrate or Prussian blue, and without any change of appearance either of the anode or the solution. I did not use the anode for any great length of time, but it appears to be very durable. The outer cast surface is a deep bluish black, almost like velvet, but the fractured surface is rather bright and crystalline, like fractured magnetite. The material has the disadvantage of being brittle, but is much less so than Acheson graphite. The magnetic anode is not as good a conductor as the graphite, but is, on the whole, one of the most promising anodes that I have seen. I am informed that the material is not so permanent with an alternating current, and also that it has been abandoned as an anode for the Clancy process, being found less satisfactory than Acheson's "extruded graphite." Such graphite when soaked in paraffin is said to give better results with that process.

The permanence of the magnetite anode suggests that, in this case at least, the oxide film, as suggested by Faraday, is the true cause of the passivity. In a thin film, formed in the wet way, porosities and defects of the film may be the cause of the unreliability and frequent failures. When the film becomes ruptured, exposing only the minutest spot, an intense local action begins and destruction follows. It is possible that electrolytic lining of the hollow magnetic anode with copper in a similar way, or filling it with a rod of iron or copper while still hot, might also cause shrinkage cracks in the film and similarly result in failure.

A serious defect of the magnetite anode is that it is not a very good conductor. Landolt and Bernstein* give for Swedish magnetite a resistance of 0.595 ohm per cubic centimeter, conductivity 1.68. I have found a much less resistance by testing the anode rod just de-

* Landolt, H. H., Landolt-Börnstein Physikalisch-chemische Tabellen, 3d ed., 1905, p. 724.

scribed, a result which I believe to be nearer the true value. The mean of four closely agreeing tests conducted at room temperature was 0.0319 ohm per cubic centimeter (or a conductivity of 31.4). This makes the resistance nearly 20,000 times as great as that of copper, more than 3,000 times as great as that of iron, and more than 10 times as great as that of a good electric-light carbon. This is a serious drawback. Of course if the metallic core could be used, without any failure in the protecting surface, this resistance would be much cut down. Further details from the manufacturers have not come to hand.

CATHODES.

Satisfactory cathodes, as such, are not so difficult to obtain. Many suitable substances are available. But when, as in the Christy electroconcentrating process, a cathode is desired that may serve alternately as a cathode and as an anode, the problem is not so easy.

SOLUBLE CATHODES.

Mercury and amalgamated copper cathodes are specified in numerous patented processes, but serious chemical and physical objections to using these materials have been sufficiently explained. An additional objection is the cost of the large amount of these expensive metals that must be used to obtain effective deposition from the dilute solutions required in practice. Except in certain exceptional electrolytic methods where strong solutions are used and where regeneration of the cyanide and the caustic alkali is possible, it may be said that the use of quicksilver and copper is out of the question.

SHEET ALUMINUM.

The use of sheet aluminum has been proposed by Cowper-Coles,* who claims that the cathode should fulfill the following conditions:

1. The gold should be adherent during the process of deposition.
2. The gold should be capable of being readily stripped, after removal from the electrolyzing cell.
3. The cathode should be electropositive to the gold in solution, to insure its being coated with gold on immersion.

It is affirmed that deposited gold is easily stripped from the cathodes after deposition, and claimed that the metal is recovered successfully from a solution containing 2.5 pennyweight of gold per ton and 0.01 per cent KCy. This solution is treated for 10 hours, with a flow of 15 gallons per 100 hours for every cubic foot of the deposition box, and for 3 square feet of cathode surface. Six volts

* Cowper-Coles, Sherard, Some notes on the recovery of gold from cyanide solutions: Trans. Inst. Min. and Met., vol. 6, 1897-8, p. 219.

are mentioned as being used. However, there is great danger of the cathodes decomposing the water and becoming coated with aluminic hydrate in spite of the current, and this of course would put an end to their usefulness.

The idea of using a metal electropositive to gold to prevent resolution of the gold in case the current fails is an ingenious one, and has been proposed by Bettal and Andreoli, both of whom use zinc for the purpose. It must be remembered that the zinc or aluminum can act as an electropositive metal and protect gold on a failure of the current only when the gold is deposited so loosely as to allow the solution access to the zinc or aluminum to form a couple. If the gold is deposited as a coherent sheet, as proposed by Cowper-Coles,^a no such protective action is possible. The anode and the gold-coated cathode then form the couple, and the gold dissolves if the current fails, in spite of the protective aluminum or zinc. Also, when mercury is in solution it amalgamates with the aluminum of the cathodes and causes the latter to heat, oxidize, and disintegrate in a most remarkable manner. In my judgment, these objections suffice to invalidate the use of aluminum for cathodes in cyanide solution.

INSOLUBLE CATHODES.

HARD CARBON AND GRAPHITE.

Hard carbon and graphite can be used in the form of sheets, both as cathodes and afterwards as anodes, in a stripping solution of pure cyanide at a low voltage without any difficulty whatever. When the gold has been concentrated on Acheson graphite sheet cathodes it may be readily stripped for the mint. It does not even need to be melted down.

There are, however, four objections to such electrodes: (1) Sheet electrodes do not offer sufficient surface to permit of rapid precipitation from dilute solutions. See the comparison of results in using sheet-iron and iron wire-cloth cathodes (p. 110). (2) Graphite and carbon in other ordinary forms are brittle, and electrodes of these materials are easily broken if much handled. (3) On account of the friable character of the material it is not possible to design a compact deposition box, as the cathode sheets must be at least one-fourth to three-eighths inch or more thick, whereas with wire cloth five times the precipitating surface may be provided in the same space. (4) The electrodes are costly. However, notwithstanding all these drawbacks it must be said that such electrodes furnish a physically workable solution of the difficulty.

^a Cowper-Coles. Sherard, Some notes on the recovery of gold from cyanide solutions: *Trans. Inst. Min. and Met.*, vol. 6, 1897-8, p. 219.

SHEET IRON.

Gold comes down very well on a surface of sheet iron; but, as already pointed out, the defect of plane sheets is the lack of sufficient precipitating surface. I have not found it necessary to scale the sheet iron by pickling; the electrolytic current soon precipitates enough gold and silver to cover the magnetic oxide scale, and in time the action even will cure rusted surfaces. It is, of course, an added expense to subject electrodes to pickling, and the cost of this would be considerable. The method of pickling suggested by Julian and Smart^a is as follows:

We have also used iron with success (as cathodes), and we find that in order to get the best results all the oxides should be removed from its surface. This we have done by immersing the plates in the following mixture: 100 parts of water, 10 sulphuric in which 1.5 of zinc is dissolved, and then adding 10 of nitric acid. If then washed in an abundance of water and kept in an alkaline solution they remain nearly as bright as silver. In this state they receive a perfectly uniform deposit. Lead can not be used to remove the deposit, as this injures the iron surface for reuse, but if placed in narrow iron boxes containing 2 to 5 per cent KCy solution and connected with Daniell cells in parallel to form the anode, while the box is the cathode, the gold and silver rapidly dissolve off without reprecipitating, leaving the plate perfectly bright and clean and ready to go back into the precipitating box.

The solution is then evaporated to dryness and melted to get the gold.

This method would be more expensive than ordinary pickling, but I can testify that it gives good results. The plates remain bright in alkaline solutions almost indefinitely. Even when used as anodes, with a voltage below 1, such plates stand up fairly well, but at higher voltages they oxidize as badly as ordinary iron. The metal can hardly be said to be "passive" when it acts as a cathode. It is possible that a film of zinc forms on its surface, although this seems improbable in the presence of nitric and sulphuric acids, or the film may be nitride of iron. At any rate the surface seems to be more permanent than "pickled" iron surfaces usually are.

As I have already pointed out, the intermittent nature of the experiments introduces a difficulty that would not occur to the same extent in continuous operation. At the end of a run the iron wire-cloth cathodes with gold or silver deposited on them had to be removed from the cyanide solution. It was not feasible to dry them by artificial heat, because the uneven expansion of the metals might cause scaling. If allowed to dry in the air at room temperatures the dampness of the wires soon caused local action, gold and silver were attacked slightly and dissolved in the cyanide solution with which the wires were wet, and after the cyanide was exhausted the

^a Julian, H. F., and Smart, Edgar, Cyaniding gold and silver ores, 1904, p. 140.

iron began to rust by local action under the coating. This trouble appeared when the cathodes were again returned to the deposition box, and, as has been seen, during the first hour or more the gold and silver dissolved in spite of the current. Not until the rust had been reduced was the gold again precipitated. In continuous work the cathodes would remain in the deposition box till they were to go into the stripping box, and when stripped they would go back into the deposition box. The difficulty would not then appear to the same extent. However, it was highly desirable to cure the evil altogether.

Many devices were resorted to. Among others the cathodes were immersed in gasoline or refined petroleum as soon as removed from the deposition box. As these liquids contained no oxygen, it was hoped to preserve the cathodes from rusting. They have such an effect, except at some points where occluded oxygenated water remained and acted. But a worse evil arose. The gasoline, like all petroleum products commercially applicable, contained so much dissolved heavy hydrocarbon that when the cathodes were removed for use an insulating residue was left on the entire surface, rendering them almost nonconductors. It is possible that the cathodes might have been preserved if they had been dried in vacuum and kept in a vacuum. But this did not appear to be practicable.

Heating the iron-wire gauze to redness in an atmosphere of ammonia gas was tried. Hydrogen was set free and nitride of iron of a silver-gray color formed, and the cathodes no longer rusted in any ordinary atmosphere. A piece of such gauze so treated has been exposed 10 years to the atmosphere of the laboratory without perceptible change. But the treatment had made the wire brittle as a pipstem, and when used as an anode under a strong current it failed as before. Possibly such a treatment might be used if it were not pushed too far, but the extreme brittleness resulting led me to drop the method.

PLATINUM.

Cathodes of platinum-wire gauze of 16 meshes to the linear inch, of 0.5-mm. wire, united like those of iron-wire cloth into "bunches of five," would be satisfactory as regards both rapid precipitation and perfect stripping. Some method of rapid drying would still be necessary to avoid resolution of the deposited metal in intermittent use, but the undercutting by rusting would have been avoided. However, calculation soon showed that the cost of such cathodes was prohibitory, and I was forced to compromise. I ordered some wire-cloth cathodes of 16 mesh (linear) to be made by Hereaus in Germany. The metal used was platinum with 10 per cent iridium, but the wires were only 0.1 mm. in diameter and the

conducting wires welded to the edge of the cloth were 0.5 mm. thick. The cathodes were made 11 by 11 cm. in size, with an ebonite frame at the edges to give the required stiffness. The section exposed to the solution was 10 by 10 cm. The 88 electrodes cost, at the price then prevailing, in 1902, nearly \$250. Seventy-two of these anodes and cathodes, with insulators, could be compacted into an 8-inch length of box with an effective section 4 by 4 inches, or into 128 cubic inches, or 0.074 cubic foot. That would have made a total cost for electrodes of \$2,900 a cubic foot. At the rate of even 1,000 cubic feet of solution treated a day in such a box, or 31 tons a day, or 11,315 tons a year, the interest on the cost of the platinum would be \$145 a year, or \$0.0128 per ton of solution precipitated. At the present prices of platinum this item would be far greater. The cost alone would be excessive; but the platinum cathodes at the start had only one-fifth the precipitating surface of the iron ones, and the precipitation was at only about half the rate at best. As they became coated with gold and silver, however, the area would increase, and the precipitating rate would increase correspondingly until the gauze would be choked with deposited metal.

The use of iron-wire gauze electroplated with platinum, or composite wires with an iron core and a platinum face drawn down through draw plates, might be feasible. But I had doubt as to whether a layer of platinum as thin as it would be economical to employ would be impervious to the OH ions. If the platinum were not impervious, the electrode would soon be destroyed. The ends of the composite drawn wires would also be a weak point for attack.

The most favorable ratio between wire diameter and distance between wires to give maximum depositing area with minimum resistance to flow of solution is when the diameter of the wire is one-third the distance between the wires, center to center, as can easily be shown mathematically. If this ratio is maintained, the total wire surface (warp and woof together) is a little more than that of both sides of a solid sheet of metal. Diameters of wire between 0.5 and 1 mm. give the best results.

IRON-WIRE CLOTH.

The many advantages of iron-wire cloth cathodes, such as the large precipitating area, the dense current that they will endure, their great permeability, and the compactness of design which they lead to, have made me very reluctant to abandon them. As before explained, the oxidation by "local action" between experiments followed by subsequent rusting and resolution would not occur in continuous use. Very little oxidation occurs in the stripping box if the stripping current is kept below 1 volt. In order to prevent leaving the electrodes too

long in the stripping box, which would be wasteful of current and would be attended with other bad effects as is claimed by Uslar,^a they could be suspended in the box by using a device like Roseleur's plating balance described by McMillan.^b This could be made to break the stripping circuit automatically and sound an alarm if thought necessary. Anodes of carbon or of melted magnetite could be used when desired to recover the dissolved gold in sheets at a slightly higher voltage from the clean-up solution. As the stripped cathode that has served as the anode of the clean-up box would be wet with a rich solution, and would have suffered an incipient oxidation, it would be inserted first as cathode for a few minutes in the so-called "hospital cell." This cell would contain 1 or 2 per cent caustic potash or soda, and with 4 or 5 volts a strong current giving a violent evolution of hydrogen would soon bring back any oxidized spots into such a state that they would be at once effective when again inserted in the deposition box.

When iron-wire cloth cathodes have become badly rusted they are easily brought into normal condition by heating in a closed iron box to about 400° C. (below red heat) in an atmosphere of hydrogen, carbon monoxide, or vapors of gasoline. Care must, of course, be taken to displace the air from such receptacle by the reducing vapor before applying the heat. The excess vapor used for the reduction would be burned, outside the box, in a suitable burner to furnish the heat necessary for the reaction. The cathodes, when badly rusted, may be brought back to duty by immersing them in powdered charcoal and heating them to a temperature below redness. Care should be taken not to overheat and melt them.

PERVIOUS CATHODES OF BROKEN COKE, CARBON, OR GRAPHITE.

In order to escape the difficulties with the iron-wire cloth cathodes I have tried also pervious cathodes composed of $\frac{1}{8}$ -inch fragments of hard coke, as well as retort carbon and graphite. Cathodes of these materials were formed by placing the material in boxes having cheesecloth sides, so that the solution could flow through the mass. On April 5, 1904, I was granted United States patent No. 756328 for a process of recovery of gold and silver from cyanide solutions along these lines. Figures 30 and 31 taken from the patent specifications will serve to illustrate the devices used.

The general process is shown in diagram 1, figure 30. *B* is the storage tank for the solution; *A*, the deposition box or electrochemical cell. The figures shows the anodes *d* (marked +) and the

^a Von Uslar, Manuel, and Eriwein, Georg, *Cyanid-Prozesse zur Goldgewinnung*: Monograph. angew. Elektrochemie, Halle, Germany, 1903, 100 pp.

^b McMillan, W. G., *Treatise on electro-metallurgy*, 3d ed., 1910, p. 101.

cathodes e , marked with a minus (—) sign. These are connected in parallel with a shunt-wound or separately excited dynamo D , provided with a suitable ammeter F and a voltmeter C . The solution

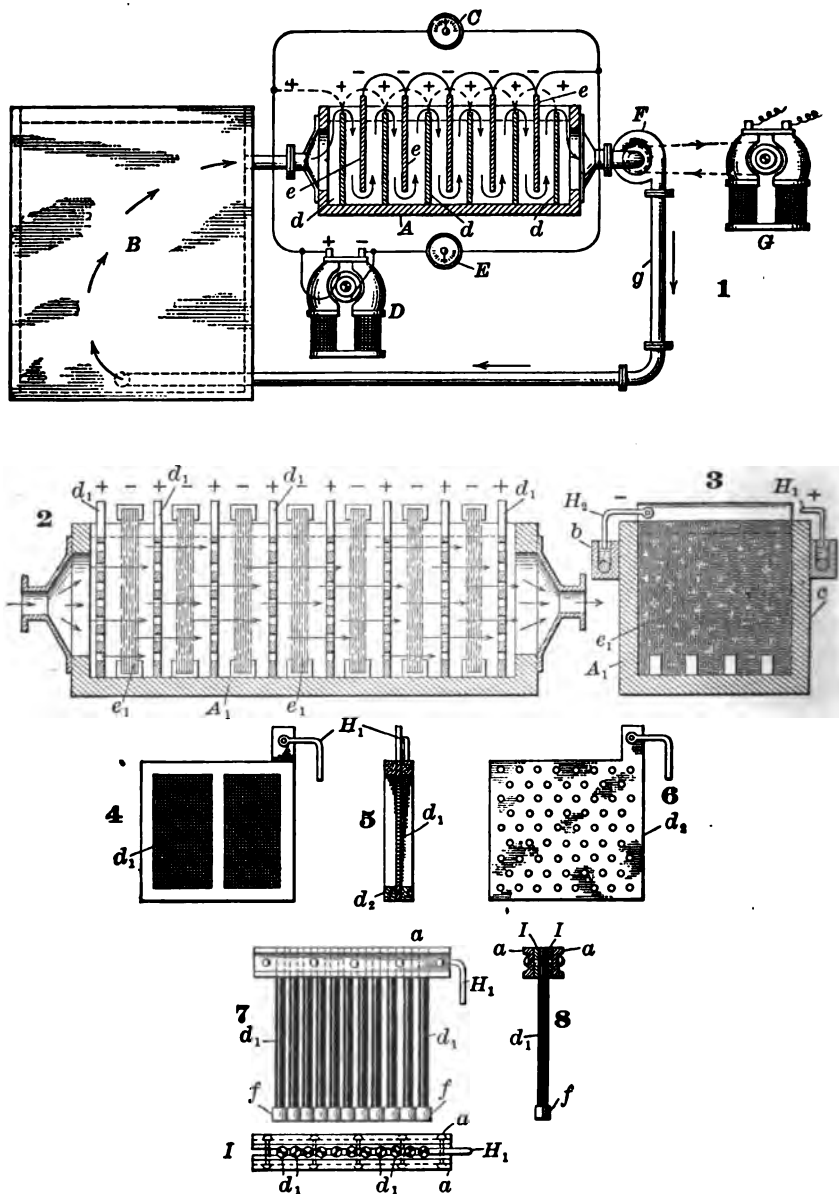


FIGURE 30.—Apparatus for recovery of gold and silver from cyanide solutions.

flows through the deposition box A from the tank B through a suitable centrifugal pump F , driven by a motor G , and back again through pipe g to the tank, and so on, rapidly, continuously, and

repeatedly and in such a manner that the solution is brought into intimate contact with anodes and cathodes in rapid alternation until

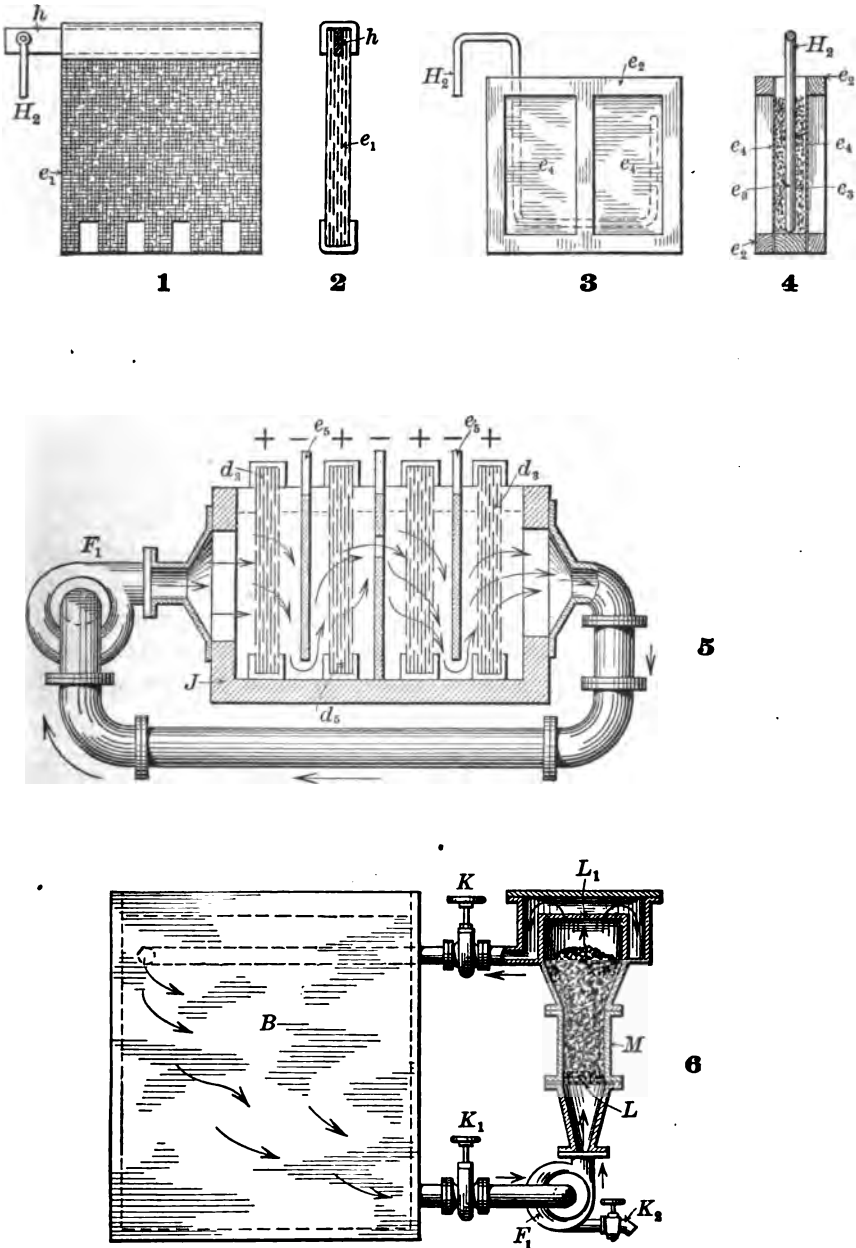


FIGURE 31.—Details of electrodes and of deposition box. Lettering similar to fig. 30.

the gold and silver content has been sufficiently reduced, when the solution is discharged and a new lot treated.

Diagram 1 of figure 30 shows also the common form of deposition-box A , with removable cathodes c . The solution flows in a zigzag course through the box, as is indicated by the arrows; but the form of deposition box or electrochemical cell that I prefer is one with pervious electrodes, as shown in diagrams 2 and 3, figure 30. In these diagrams the box is designated by A_1 , the anodes, d_1 , are marked with the plus sign (+). The anodes are made of any electroconducting substance not too much acted on by the solution, such as iron, lead, peroxide of lead, platinum, or, for pressures not greatly exceeding 1.5 volts, dense carbon or graphite. These anodes may be constructed of wires, rods, gauze, or perforated sheets, in any form or manner to be pervious to the solution. The wire-gauze d is best mounted to prevent contact with the cathodes, in a parafined wooden frame d_2 as in diagrams 4 and 5, figure 30, connected electrically with an amalgamated copper wire H_1 . The perforated sheet-metal anodes d_2 are constructed as in diagram 6, figure 30. The graphite or carbon anodes may be similarly constructed of perforated blocks; but I prefer to construct them of the densest graphite or electrode-carbon rods d_1 , mounted, as in diagrams 7, 8, and 9, figure 30, in which a represent parafined wooden frames, inclosing electroconducting strips I , which are connected with the amalgamated copper wire H_1 . The electroconducting strips make electric contact with the carbon rods placed about one-eighth inch apart. At f short strips of rubber hose are shown which prevent contact with the cathodes.

METHOD OF PREPARING AND USING PERVIOUS ELECTRODES.

When wire-cloth cathodes are used the wire cloth is cut to a size to fit the box, and the sheets e_1 are clamped together, as in diagrams 1 and 2, figure 31, in bunches of five or ten sheets, electrically connected with a sheet-iron strip h , to which is riveted an amalgamated copper wire H_2 . Before the sheets of wire gauze are clamped together they should be preferably heated to dull redness for about one minute to burn the oil usually left on the surface by the manufacturer and to coat them with a thin coating of magnetic oxide of iron. They should not be exposed to the heat too long or a thick scale forms that easily cracks off.

Instead of iron-wire gauze any other pervious conducting substance may be used as a cathode, such as metallic filaments or cloth saturated with precipitated silver, gold, or other metal, thus exposing a large surface. A metal surface of this kind may be prepared by inserting a sheet of metallic wire cloth (of iron, for instance) as a basis for a cathode, into a suitable electrochemical cell provided with pervious anodes. Through this cell is circulated a strong solu-

tion of gold, silver, copper, lead, or other electronegative metal, during the passage of a dense electric current, to precipitate such metal on the surface of the wire cloth in a pervious or spongy layer. This forms an electrolytic filter of enormous cathode area in a small compass. The anodes and cathodes thus formed may be arranged as shown in diagram 2, figure 30, or they may be arranged horizontally one above the other and the dilute cyanide solutions from which the gold and silver are to be removed may be forced to circulate rapidly through such pervious anodes and cathodes.

Also, for the purpose described, granulated metal, pulverized coke, or electrocarbon dust e_3 , properly sized, may be placed in a wooden framework e_2 , covered with cheesecloth e_4 , and electrically connected by an iron wire ending in an amalgamated copper wire H_2 , as shown in elevation in diagram 3, figure 31, and in cross section in diagram 4, figure 31. The electrodes are separated one-half to one-fourth inch to prevent short-circuiting. In diagrams 2 and 3, figure 30, is shown the arrangement of such a deposition box with pervious anodes and removable pervious cathodes. Electric connections in parallel are made with the anodes and cathodes, as shown in the sectional view 3, figure 30, by the box b , connected with the negative pole, and by the box c , connected with the positive pole of the dynamo. The wooden boxes b and c contain omnibus bars of amalgamated copper and connecting holes filled with mercury, into which dip the wires H_1 from the anodes and the wires H_2 from the cathodes.

The box A_1 , shown in diagrams 2 and 3, figure 30, is placed in the position shown for box A in diagram 1, figure 30, being substituted for that box, and the solution is forced to circulate repeatedly from tank B through the box A_1 and through the pervious anodes and cathodes, and back again, so as to be brought into intimate contact with anodes and cathodes in rapid alternation until its gold and silver content is sufficiently reduced. When the voltage is kept constant at any point (at two volts, for instance) the completion of the treatment is indicated by the number of amperes of the electric current. The number is high at first, but suddenly drops and becomes constant when the gold and silver content of the solution is exhausted. Since the fall of electric current could be caused by an accidental increase of resistance, it is necessary always to assay the solution before discharging the lot under treatment.

I prefer to concentrate the gold and silver thus deposited on removable cathodes in the manner shown in my former patent, No. 643096, February 6, 1900. However, I have been able to increase the precipitating capacity of the deposition box by the new method described here to far exceed the capacity of the clean-up box there shown. I have also been able to apply the same principle of rapid

circulation to that box, and thus to increase its capacity. Diagram 5, figure 31, shows how this is effected. A centrifugal or other pump F_1 forces the cyanide solution, which should be as free as possible from chlorides and sulphates, to circulate rapidly through the clean-up box J , preferably, though not necessarily, at such a rate as to prevent the evolution of gas at the cathodes. These consist, preferably, of sheets of iron e_s , marked with a minus (—) sign in the figure and arranged, as shown, to force the solution to pass alternately up and down through the box and at the same time through the pervious secondary anodes d_s , marked with a plus (+) sign. These secondary anodes are the gold and silver laden primary cathodes e_1 , from the deposition box, shown in diagrams 2 and 3, figure 30. Although pervious cathodes e_1 to collect the silver and gold in the deposition box are preferable, impervious cathodes, e , shown in diagram 1, figure 30, can be used. The gold and silver content is then concentrated on the secondary cathodes in a similar manner. The secondary cathodes e_s , of sheet iron or other metal, marked minus (—) are, before being inserted in the clean-up box, coated with a very thin layer of electroplater's graphite and vaseline. With an electromotive force of about one-half volt, the gold and silver are rapidly removed from the removable secondary anodes d_s (primary cathodes e_1 in the deposition box) and deposited on the secondary cathodes e_s , as solid sheets. These sheets may be pulled off at convenient intervals and are ready for the mint without further treatment. I have thus produced solid sheets of bullion one-eighth of an inch thick and 996 fine. If an extremely dense electric current is used in the clean-up box, the gold and silver will be deposited on the secondary cathodes in the form of a loose powder, which is easily removed with a stiff brush and can be melted down into bars. The rapid circulation of the solution permits the concentration of the metal with a dense current, and greater rapidity is insured in a small box.

Also, it is evident that, instead of having two separate boxes—a deposition box and a clean-up box—the same result may be obtained with a deposition box that serves both purposes in alternation. This is particularly the case when pervious cathodes of broken carbon or graphite are used, for these are bulky and inconvenient to remove to a clean-up box. Instead of doing this, when the cathodes become sufficiently charged with gold and silver in the deposition box after the circulation of a large volume of cyanide and ore solution, the circulation from the storage tank is cut off. Then the same or a fresh cyanide solution is made to circulate rapidly and repeatedly through the box (see diagram 2, fig. 30) by means of a pump, as in diagram 5, figure 31, except that now the primary cathodes of diagram 2, figure 30, marked minus (—), are connected with the plus

(+) pole of the dynamo, to become secondary anodes, while the original anodes (diagram 2, fig. 30), marked plus (+), are replaced by secondary cathodes of sheet iron which have been previously coated with a mixture of graphite and vaseline. The secondary cathodes on being connected with the negative (—) pole of the dynamo become coated with the gold in a concentrated form, which had been previously distributed on a very large primary cathode area. The secondary cathodes may be of the form of those marked minus (—) in diagram 5, figure 31, or they may be as shown in diagram 6, figure 30, or they may be of separate strips of iron or other conducting material, arranged like the slats of a window blind, so as to be pervious to the solution. It is preferable to circulate the solution at such speed that evolution of hydrogen gas is practically avoided at the cathode; if, owing to the density of the electric current used, this is not possible the velocity should not be less than 1 foot per minute. When the gold content of the original cathodes, now secondary anodes, has been recovered, the secondary cathodes, now laden with concentrated gold, are removed, the original anodes are replaced, the electric connections changed to the original condition, and the stock solution turned again through the tank, which now serves as a deposition box, as shown in diagrams 1 and 2, figure 30.

The same principle of rapid circulation and repeated treatment in rapid alternation of a large volume of solution in a small deposition box containing pervious electrodes may also be applied to the electrochemical recovery of gold and silver from cyanide solutions without the use of a dynamo or external source of electricity, the electric energy being furnished by such an electropositive metal, as zinc, in the form of fine granules, shavings, or dust. This system is shown in diagram 6, figure 31. The figure shows at *B*, the large storage tank containing the solution to be treated, a centrifugal or other pump *F*₁, and a vessel *M*, containing zinc in the form of shavings or other form, exposing a large surface. The zinc rests on a filter *L*. A filter *L*₁ may be used at the top of the box to avoid the loss of fine particles, if desired. *K*, *K*₁, and *K*₂ represent valves to control the flow. The solution is forced to circulate from the tank *B* through the zinc and back again repeatedly (preferably, though not necessarily) at such a rate as to substantially prevent the evolution of hydrogen. The gold and silver are rapidly precipitated by the electrolytic action set up between the solution and the zinc. The zinc particles act as anodes and the gold and silver particles, which are at once deposited in a porous or pervious state upon the zinc, act as cathodes. The zinc anodes covered with this pervious coating of gold and silver form a combination of pervious anodes and cathodes, and when the solution is forced to circulate rapidly and repeatedly through them it is brought into intimate contact with anodes and

cathodes in rapid alternation. Although the electromotive force of the combination is small, the current is short-circuited, and the resistance therefore is smaller than in any other form of cell, and hence the gold and silver are rapidly precipitated. In this type of process it is important that the gold and silver be precipitated on the zinc in a loosely adherent porous film in order that the zinc and the precipitated metal form a set of electrodes pervious to the solution. In some instances the precious metal forms a solid impervious film on the surface of the zinc. When this happens, precipitation ceases. In such an event the zinc, before use, should be coated by dipping it into a dilute solution of nitrate of silver or acetate of lead, forming a pervious film of silver or lead. When the zinc is sufficiently fine the precaution is unnecessary.

By the ordinary zinc process, owing to local action, 5 to 20 ounces of zinc are required to precipitate 1 ounce of silver or gold, but with the Christy process practically complete precipitation of 1 ounce of silver with 0.57 ounce zinc has been effected, and results nearly as good with gold. In practice the use of about 2 ounces of zinc to 1 of gold and silver is preferable, but even then the use of the process will save zinc and reduce the cost of refining the precipitate.

By the application of the same principle the precipitate can be refined without the use of acid by circulating rapidly and repeatedly a solution of cyanide, nitrate, or sulphate of silver, of cyanide or chloride of gold, or soluble salt of copper, through the precipitate, so that such solution may come into contact, in rapid alternation, with the residual particles of zinc, acting as pervious anodes, and of deposited gold and silver, acting as pervious cathodes, until the residual zinc is dissolved. After refining the precipitate in this manner the silver or gold, left in the refining solution, is recovered by the use of fresh zinc, as before.

Most of my work, though not all, was done with pure solutions, and desiring to see how the process would work with stock solutions from the treatment of ores, I obtained in 1905, through the kindness of Mr. Charles Rhodes, manager of the Waihi mine, New Zealand, and of Mr. W. W. Mein, general manager of Robinson mine, Johannesburg, an opportunity to have tests made at these places.

I much appreciate the trouble the experimenters took with these tests, but none of the experiments were carried out exactly as I directed. In some tests the lack of facilities at hand made this impossible; in others the ideas of the experimenter led to changes in details without realization of the detrimental effect. Most serious of all was the failure to record all the necessary variables. Thus the causes of success or failure in many of the experiments can not be determined. Circulation by means of the pump, which should have been easily controlled, was found troublesome and results in

some tests seem to indicate that the boxes did not get the proper treatment. I present here the results obtained by other men in tests conducted at my request as described.

EXPERIMENTS AT WAIHI MINE, NEW ZEALAND.

The experiments at Waihi mine, New Zealand, were conducted by Herbert W. Hopkins, metallurgist, Victoria mill, Waikino, in 1905.

The solution employed for these tests was that which had been used in treating a clean gold and silver bearing quartz ore containing 1 per cent pyrite. The solution was heavily charged with lime to settle the slimes. The box used was 3 feet 4 inches by 1 foot by 10 inches. The electrodes were immersed to present an area 11 by 9 inches, which later was increased to 11 by 10 inches.

EXPERIMENTS WITH FLAT OR PLANE ELECTRODES.

SERIES A TESTS.

Both the 29 anodes and the 28 cathodes were of lead. No trouble is mentioned with respect to the anodes, and it is presumed that they were peroxidized. The cathode area exposed was 38.5 (later 42.8) square feet for both sides and all electrodes were spaced one-third inch apart. Allowing one-eighth inch for thickness of lead, we have 1.66 cubic feet as the volume of box actually occupied by electrodes. The capacity which I claimed such a box should possess was 8.30 cubic feet per 24 hours.

Twelve experiments were made with a single flow through the box at a rate varying from 0.75 to 0.87 long ton, or 26.7 to 31 cubic feet per 24 hours, which is three to four times the capacity claimed for such a box. With 2.5 to 3 volts and 3.5 to 3.8 amperes and an average current density of about 0.1 ampere per square foot, the average of 12 experiments was a recovery of 32.3 per cent gold and 31.2 per cent silver, with a reduction in cyanide content of the solution from 0.142 to 0.138 per cent. If the volume treated had been reduced to 8.3 cubic feet per 24 hours, the results would undoubtedly have been much the same as I have obtained.

SERIES B TESTS.

Three experiments were conducted with 6.1 cubic feet of solution passed four times through the cell in 3 hours, which would be at the rate of 48.8 cubic feet per 24 hours. With 2.5 to 3.5 volts and 3.5 to 10 amperes no gold was obtained. The current density here was 0.26 ampere per square foot, or nearly the same density as that used by Mr. Butters to deposit metal as a slime, and the rate of passage of the solution was about 5.88 times that which I have desired. The

velocity of flow of solution through the narrow slit between the plates, $\frac{1}{4}$ by 11 inches, would have to be more than 5 feet per minute to give this flow, hence it was to be expected that the loose slimy deposit would be stripped from the flat plates by the excessive flow.

SERIES C TESTS.

In this test the rate of flow was 0.92 long ton or 32.15 cubic feet per 24 hours, nearly four times the desirable capacity of the box. At 4 volts and 10 amperes and with a density of current amounting to 0.26 ampere per square foot the recovery of gold was 61.7 per cent and of silver 59.3 per cent, with no loss in cyanide. Considering that this is nearly four times the desirable capacity of the box, the results are not bad. The current density was sufficient to deposit slime on the flat electrodes, but the circulation was not sufficiently violent to wash it all off. Another experiment, at the rate of 0.9 long ton per 24 hours, gave 60.7 per cent recovery of gold and 59.8 per cent of silver.

In all the above experiments with flat electrodes the volume of solution was three to seven times greater than the capacity which I should have desired. As the duration of the tests is not mentioned the ampere-hour efficiency can not be calculated.

EXPERIMENTS WITH PERVIOUS WIRE-CLOTH CATHODES.

The solutions employed in the tests with pervious cathodes contained 7 to 25 pennyweights of gold per long ton, 1 to 3 ounces of silver, and 0.14 to 0.22 per cent potassium cyanide. The 28 cathodes and 29 anodes were spaced one-half inch. Each cathode was a single piece of 16-mesh iron-wire cloth, the total area being about 34 square feet. The anodes were of sheet lead resting on the bottom of the box and perforated by 80 one-half inch holes. These should have been five or ten times as numerous.

For the test a measured quantity of solution was placed in a barrel at the head of the deposition box, also filled with the solution. The current was allowed to run from the barrel through the box to a second barrel which received the tailing. At the end of the test the content of this tailing barrel was transferred to the head barrel. Later, after experiment 25, two head and two tailing barrels were used, to make sure that every part of the solution received its proper treatment.

Three interesting experiments, which will be here designated A, B, and C, were made to determine the effect of a stoppage of the dynamo. The conditions of test and results were as follows:

A. Solution standing in cell; dynamo stopped; brushes down; circuit not broken. Sample taken when dynamo stopped: Gold content, 5 pennyweight 5

grains; silver, 14 pennyweight 21 grains. Sample taken after standing 16 hours: Gold content, 6 pennyweight; silver, 16 pennyweight 5 grains.

B. Solution standing in cell; dynamo stopped; circuit broken. Sample taken when dynamo stopped: Gold, 15 pennyweight 12 grains; silver, 2 ounces 2 pennyweight 9 grains. Sample taken after standing 20 hours: Gold, 16 pennyweight 11 grains; silver, 2 ounces 5 pennyweight 20 grains.

C. Solution standing in cell; dynamo stopped; circuit broken. Sample when dynamo stopped: Gold, 5 pennyweight 23 grains; silver, 9 pennyweight 11 grains. After standing 1½ hours: Gold, 5 pennyweight 21 grains; silver, 10 pennyweight 18 grains.

The longest stoppage that occurred during which the circuit was broken was one hour.

Allowing one-eighth inch for the thickness of the electrodes, which were one-half inch apart, the electrodes occupied 2,200 cubic inches, or 1.25 cubic feet. Thus the box was much less compact than those which I have used with wire-cloth electrodes, in which the current gap was never more than one-fourth and often less than one-eighth inch, and in which I never found indications of short circuits.

DISCUSSION OF RESULTS.

It will be observed that the best results of the experiments between Nos. 21 and 28 were obtained with rich solutions, test 24 giving the best results of all. The experiments ran too short a time, probably because the handling of the barrels was too onerous. The centrifugal pump would have removed that difficulty. If the cathodes were intermittently used, rusting and subsequent stripping must have taken place and lowered the results during the short time of the test.

In experiment 36 the wire cloth was 8-mesh. Only three sheets were placed between each cathode; hence adequate depositing surface was not provided. Though most of the solution passed beneath the cathodes, some must have passed through. The cathodes had evidently rusted with some gold and silver upon them from a previous experiment. This corresponds with my own experience. Then when the cathodes were used in experiment 36 the gold and silver immediately redissolved where the cathode had rusted, and until the rust was removed the current was wasted in reducing the iron oxide. The silver, being easier to reduce, came down first. Experiments 37 and 38 seem to show that the cathodes were in better condition; and though the current density is still high, the ampere-hour efficiency is fair. If these experiments had been conducted exactly as directed, the results obtained would have been better. Foul mill solutions are harder to treat than clean solutions. I have successfully treated many such solutions, as well as similar solutions saturated with lime. The solutions at the Waihi mine contained, among other substances, selenium, probably as selenate of sodium,

which is usually recovered with the gold and silver in the zinc clean-up. The real difficulty in the last experiments was doubtless the rusting of cathodes, through intermittent use. One of the cathode plates sent me, though carefully packed, was covered with rust.

EXPERIMENTS AT TRANSVAAL GOLD MINING ESTATES.

Some experiments were made with iron-wire cloth cathodes at Transvaal Gold Mining Estates, Pilgrim's Rest, South Africa, by A. Scrymgeour in August, 1905. The description given here is condensed from a report presented by him to W. W. Mein. The precipitation box used was of 1 cubic foot capacity, the cross section not being stated. The anodes were one-sixteenth inch iron plates with one-fourth inch holes. The cathodes were of wire gauze, the mesh, area, and construction not being stated. The first experiments were made with working solutions containing an average of 4 penny-weights gold per ton, copper as a double cyanide, and 0.016 per cent and 0.0087 per cent cyanogen and protective alkali. A long series of experiments gave an average precipitation of about 25 per cent of the gold after a half hour's contact.

The average precipitation of our ordinary Siemens and Halske box is 75 per cent for four hours' contact (eight times as long), so that the Christy method panned out appreciably better, but against that there is the fact of clean anodes and higher amperage. As there was, however, a considerable discrepancy between these results and Prof. Christy's, a clean solution of sodium aurocyanide was made up and a series of experiments done therewith.

The precipitation was most exceptional—75 to 80 per cent on half an hour's contact. With clean solutions of aurocyanide the iron plates were scarcely attacked, but with working solutions the plates became extremely foul with iron and copper cyanides and had to be cleaned up every week, the resulting "blue" containing 7.9 ounces to the ton, which is extremely high for so short a period.

With working solutions the free cyanide was consumed to the extent of about 25 per cent.

The very high rates of flow (1 foot a minute) mentioned in Prof. Christy's paper gave practically no precipitation. One foot in four minutes seemed most effective in our experimental box.

The wire-gauze cathode gave a very nice and clean deposit.

In this brief report some details are missing. The section of the cathodes, the skin area of their surface, the current density, the current, and the voltage, are not stated; therefore it is not possible to explain the low result obtained at the rate of flow of 1 foot per minute. With the foul solutions treated, iron anodes should not have been used, but, instead, perforated peroxidized lead anodes. The presence of copper, moreover, introduces difficulty in the precipitation of the gold by any process, as will be considered later.

EXPERIMENTS WITH PEROXIDIZED ANODES.

These experiments, like those previously described, were conducted in the latter part of the year 1905 by A. Scrymgeour on copper and gold bearing cyanide solutions. The lead plates were peroxidized in permanganate of potassium solutions and were one-fourth inch thick, with five-eighth inch holes. The holes were too large and were probably too few in number. The results were better than with iron anodes.

"The cathode gave, upon the whole, a good deposit, but a slight furring of the copper was noticed at the higher amperages." The solutions treated contained 0.046 to 0.065 per cent copper, 0.004 to 0.006 per cent alkali, and 0.0064 to 0.013 per cent cyanide. The rate of flow varied from one-eighth to one-third of a foot per minute, and the current was 0.014 to 0.033 ampere per square foot of cathode surface. The original content of gold was 1.05 to 2.2 pennyweights, which after one hour became reduced to 1.25 and 0.3 pennyweight, with 16 to 71 per cent recovery. In this and in other experiments there were evidences of cathodes having rusted from intermittent use.

In one test a clean solution of sodium aurocyanide was treated, the rate of flow being one-eighth foot per minute and the current 0.014 ampere per square foot. The original content was 2.2 pennyweights, becoming reduced after one-half hour to 0.40 pennyweight, and after one hour to 0.10 pennyweight, showing an extraction of 95 per cent. In only one or two tests was there any evolution of gas. The current density used by Siemens and Halske is given as only 0.006 ampere per square foot, and Scrymgeour, judging by that, evidently thought it best not to push the current density too far. The density, however, was not sufficient to insure a good precipitation. The best results were obtained with the higher current densities.

EXPERIMENTS AT ROODEPORT CENTRAL DEEP, 1905.**FIRST GROUP TESTS.**

In 1905 some experiments were made at Roodeport Central Deep mines, in South Africa, by Gabriel Andreoli. In these experiments, after some preliminary work with low current densities, similar to those usual in the Siemens & Halske process, the box was operated at such a density as "to just allow a slight evolution of gas to be visible at the electrodes." To quote further from Andreoli's report:

The results of this experiment being in my opinion very encouraging, it will perhaps be interesting if I give full details:

Space of box occupied by anodes and cathodes, slightly under 1.5 cubic feet, say 90 pounds.

Flow of solution through box maintained during the experiment at 1 per minute (0.0642 cubic feet per minute or a velocity through box = 0.7 per minute) = duty 64 times capacity of box.

Twelve anodes 1 foot square of $\frac{1}{8}$ -inch sheet iron perforated with holes; 24 cathodes in pairs, each cathode consisting of five sheets screening clamped and connected together, $\frac{1}{4}$ -inch space between anodes. Current at start 10 amperes, slight evolution of gas apparent subsequently reduced in stages to 7 amperes, maintaining evolution at electrodes.

KCy and alkalinity tested right through the experiment; and practical alteration, KCy 0.068 per cent, alkalinity expressed as NaHO = 0.021 per

Value of solutions:

Before first circulation, 8.04 pennyweights per ton.

After first circulation (drip sample at foot of box) 1 pennyweight per ton.

Recovery, 87.5 per cent. Duty, 64:1.

Before second circulation 3.66 pennyweights per ton.

After second circulation 0.6 pennyweight per ton.

Recovery, 81.4 per cent. Duty, 64:1.

Total recovery, 91.5 per cent. Duty, 32:1.

If it had not been for the accident of mixing the 1-pennyweight solution some of the original solution I feel certain that the total recovery would have shown a more striking figure.

As it is I consider this very successful as compared with the Siemens & Halske process which in this plant gives an average recovery from solution only 70 per cent and the duty compared to capacity being 2.5:1.

The experiment, however, seems to contradict Prof. Christy's claims that the process is economical from an electrically efficient point of view. I may have succeeded in obtaining good precipitation with a lower current density, but was in this experiment extremely high, namely, 0.3 ampere per square foot of anode surface. Normal Siemens & Halske practice here is 0.04 ampere per square foot of anode surface.

If it is found that such a high current density is necessary for successful precipitation then insoluble anodes will be indispensable; but to any one accustomed to the so-called Prussian blue produced on a Siemens & Halske, its treatment is not a formidable matter.

In the three experiments the gold precipitated on the cathodes was in the form of a bright deposit with perhaps the exception of the last experiment where the gold on the lower part of the box was inclined to be slimy, but this was to be anticipated, considering the high current density used.

In regard to the statement that the electrical efficiency is better than that which I have found it to be in my own experiments, I may say that my own experiments are perhaps a sufficient answer and that no data were given to justify criticism. The voltage, the duration of the test, the quantity of solution treated, and the average number of amperes are not given by which the results might have been calculated. Moreover, it was afterwards found that the tanks used were old chlorination tanks already saturated with gold, which introduced a handicap that no process would overcome.

SECOND GROUP TESTS.

The following description of further experiments at Roodeport, in 1905, is from the report that Andreoli rendered to Mr. W. W. Mein:

From the results I have obtained so far it is noticeable that I have only had satisfactory results on the occasions when a heavy current density has been used, and the production of by-products due to the use of iron anodes has been considerable; and on the lines which I have been working the use of insoluble anodes appears imperative. I have communicated with you, and a set of peroxide of lead anodes is being made.

As you will notice from the results obtained in experiment 6, the duty of the box is considerably higher than anything the Siemens & Halske process has approached, besides being much more effective, but the competition to be met from the Siemens & Halske process is negligible; it is the ordinary zinc precipitation which has to be met. Here again experiment 6 gave an equal precipitation result at a higher proportion of daily flow to the capacity of the box than even the zinc process and with the expenditure of more electrical power. So far as I can see, the duty of the Christy box can be raised still further until a practical limit is reached. This is what Prof. Christy has claimed all along; large quantity of solution treated in a small cubic space, but I can not up to the present indorse the economy of electrical power or electrochemical efficiency. I propose at some future date to repeat a rapid circulation experiment, such as the patent specification insists on, but the result of my No. 1 experiment and Scrymgeour's experience are not encouraging.

In the last month's experiments the cathodes (made of mill screening) received under the high-current density conditions a remarkably hard and bright deposit.

The following is a summary of the experiments made this month:

Experiment 4.—Speed of flow increased to 6 pounds per minute. Value before first circulation, 3.1 pennyweights; after first circulation (dip sample), 0.4 pennyweight; recovery, 87 per cent; duty, 96:1.

Value before second circulation, 0.88 pennyweight; after second circulation (dip sample), 0.34 pennyweight; recovery, 61 per cent; duty, 96:1. Total recovery, 90 per cent; duty, 96:1.

Experiment 5.—Current high, as in Nos. 3 and 4; speed of flow increased to 10 pounds per minute. Duty, 160 times capacity of box. Evolution of gas only apparent at lower end of box, and eventually, as current dropped, it had to be increased to maintain evolution of gas at electrodes. Value before first circulation, 5.4 pennyweights; after first circulation (dip sample), 1.2 pennyweights; recovery, 77.77 per cent; duty, 160:1.

Value before second circulation, 1.52 pennyweights; after second circulation (dip sample), 0.54 pennyweight; recovery, 64.51 per cent; duty, 160:1. Total recovery, 90 per cent; duty, 80:1.

Experiment 6.—Considering that the experiments summarized above were very satisfactory from the point of view of duty, percentage of recovery, but that the lowest values of solutions were 0.34 pennyweight (experiment 4) and 0.54 pennyweight (experiment 5), this experiment (No. 6) was made on solutions of low value, to determine the possibility of reducing solutions to the low gold values which obtain in our current practice here.

Current strength as high as in Nos. 3, 4, and 5, namely, 10 amperes,

Rate of flow of solution, 4 pounds per minute. Value before first circulation, lost in assay office; after first circulation (dip sample), 0.46 pennyweight; before second circulation, 0.62 pennyweight; after second circulation (dip sample), 0.12 pennyweight; recovery, 80.64 per cent; duty, 64:1.

Experiment 7.—Since this experiment (No. 6), was fairly successful, experiment 7 was made at a higher rate of flow (6 pounds per minute); and a lower density, 5 amperes, which showed an evolution of gas right through the experiment, on the lower half of the set of electrodes. Value before first circulation, 0.5 pennyweight; after first circulation, 0.28 pennyweight; before second circulation, 0.52 pennyweight; after second circulation, 0.46 pennyweight.

This experiment I considered either salted, or incorrect, and the experiment was repeated.

Experiment 7a.—Evolution of gas profuse right through the experiment. Value before first circulation, 1.55 pennyweights; after first circulation, 0.44 pennyweight; before second circulation, 0.62 pennyweight; after second circulation, 0.78 pennyweight.

I have entered against this in my log book that the sample of second circulation must have been crossed; but now I believe that at the slow rate of flow of solution, the sample before circulation is incorrect, as the solution standing in the vats some 24 hours takes up more gold than the assay return shows.

Experiment 8.—Nos. 7 and 7a giving strong evolution of gas at comparatively low current, the rate of flow was increased to 6 pounds per minute. Results no good at all. Value before first circulation, 0.72 pennyweight; after first circulation, 0.54 pennyweight; value before second circulation, 0.56 pennyweight; after second circulation, 0.7 pennyweight.

Experiment 9.—Nos. 7, 7a, and 8 having given results of no value, No. 9 was made at the same rate of flow as No. 8, namely, 6 pounds per minute, and the current was increased to the strength used in No. 6, which gave a comparatively good result. Value before first circulation, 1.8 pennyweights; after first circulation (dip sample), 0.3 pennyweight; before second circulation (dip sample), (assay not done); after second circulation (dip sample), (assay not done).

I notice in one of your extracts from Prof. Christy's letters that he says he can reduce solutions to the value of 1 or 2 cents; but that he prefers to make it only 10 or 12 cents. This latter I have done in No. 6; but it is too high for our normal practice here, although the disadvantages might be outweighed (if it can not be overcome, which I do not believe) by the economy of initial outlay, efficiency, simplicity of clean-up, and other advantages inherent to the process.

DISCUSSION OF RESULTS.

In comment on the foregoing experiments, I can but express regret that old chlorination tanks had to be used. Evidences of the salting of the solutions at the most critical junctures are apparent. The omission of a record of the voltage and the amperage, hour by hour, of the duration of the experiment and of the volume of solution render it impossible to judge the ampere-hour efficiency. A two-barrel method of circulation is not satisfactory, for the reason that the velocity of flow diminishes with the diminishing head in the head tank, except when constantly regulated. The necessity of increasing the flow of solution as the liquid becomes impoverished of its gold and silver content can not be too positively emphasized.

It must be increased till the evolution of gas at the cathodes either ceases or becomes a minimum. Experimenters, by omitting these precautions, fail to obtain the results and the efficiency that are possible. It is true that gassing at the anodes need not be stopped, but some fail to appreciate the effect of the greater precipitating surface that I insist on. The best results are obtained by increasing simultaneously the cathode surface, the current density, and the speed of circulation. The current density should be kept at the highest point that will allow the metal to come down firmly coherent and to increase the circulation so as to reduce gassing at the cathodes to as low a point as is possible with the highest practicable current density. The limit of current density is reached when the metal comes down as a slime, and as it forms is washed off by the solution.

A difficulty that Andrioli must have met, though he does not mention it, was the intermittent use of the cathodes. From the dates of the experiments I observe that the interval was sufficient to cause the rusting of the iron wires beneath the gold. Some of the gold must have redissolved in the first part of his later experiments, and whether this was later corrected by the current can not be determined from the data given.

In Scrymgeour's experiments and Andrioli's first experiments the large amount of lime in the solution tested seems to have deterred them needlessly from employing adequate circulation. I have treated solutions rich in lime at velocities of flow of several feet per minute through gauze cathodes with no trouble from this source. With new cathodes trouble sometimes arises from a nonconducting coating of oil on the gauze or from the cathodes having been previously used and allowed to rust by intermittent use, as I believe was more probably the case.

I wish to express my hearty thanks to Messrs. Hopkins, Scrymgeour, and Andrioli for the trouble they have taken with these tests and my realization of the many limitations as to necessary conveniences and with constant interruptions. I consider the results favorable in view of the departure from the directions given and from the conditions that I would have desired.

SNODGRASS CYANIDATION APPARATUS.

A patent, of 10 claims, by J. Snodgrass (U. S. patent 835329, Nov. 6, 1906), appeared shortly after the experiments that have been described were made. The apparatus disclosed in the patent consists of a rectangular box through which the solution flows only once. The bottom of the box is covered with an iron plate, which is connected with the negative electrode. The cathodes are made of iron

frames resting on the bottom cathode plate, and either faced with iron-wire gauze of 100 meshes to the inch or with woven cloth of fine texture, coated with plumbago or with plumbago and a lead salt. The anodes are wooden boxes with coarse cloth sides, filled either with gas carbon or coke, graphite, binocide of manganese, or peroxide of lead. The solution does not flow directly through the anodes, but is shunted around them. Carbons or other conductors are inserted into the box and connected with the positive pole. The iron plate connected with the cathode is claimed to have the advantage that any metallic powders falling on it from the cathode are prevented from being redissolved. The inventor expressly disclaims the use of rapid and repeated circulation of the solution through the deposition box, and urges this omission as an advantage.

It is apparent that effective precipitation under such conditions can be procured only by making the box large and costly and the clean-up difficult and expensive. To circulate the solution around and not through the anodes sacrifices one of the benefits of pervious electrodes. The iron plate at the bottom, on which the cathodes rest, is a good feature.

"COKE WHISKERS" AS AN ELECTRODE.

While I was engaged in a systematic search through all the known elements and compounds for a substance that would serve alternately as an anode and a cathode in cyanide solutions I received a specimen of the product popularly known as "coke whiskers." This substance was produced by Dr. J. A. Holmes in some of the experiments in coking coal that were undertaken by him at the Government testing plant at St. Louis, Mo.

The product closely resembles in size, shape, and color the hair of a negro's head. It is, however, a peculiarly resistant form of coke. It is but slightly attacked by the strongest nitric acid containing chlorate of potassium. It is a pervious mass, a good conductor of electricity, presents an enormous surface for deposition, and, in short, seemed to be the substance I had been looking for. It was not a newly discovered substance, but had been previously mentioned by Percy.^a He describes the substance as follows:

Hairlike form of coke.—Hairlike threads are sometimes observed on pieces of coke. They are nearly solid, and under the microscope occasionally present somewhat the appearance of a string of beads, soldered together. They consist of carbon, which seems to have been deposited in the following manner: A bubble of tarry or hydrocarbon vapor and gas, in escaping from the surface of the coke, becomes more highly heated, and is in consequence decomposed with

^a Percy, John, *Metallurgy*; fuel. 1875, p. 421.

the separation of solid carbon, which is deposited as a continuous coherent film on the surface of the bubble; a second bubble escapes through the carbonaceous shell of the first, and is similarly decomposed, forming a second carbonaceous shell attached to that resulting from the first bubble; and so, by a continuous succession of such deposits of carbon, a continuous tube of carbon is formed. Gas would continue to flow through this tube, depositing carbon in its course on the inner surface, until at length the tube is converted into a nearly solid fiber. Such appears to me the mode of formation of this curious hairlike matter, though I am by no means certain of the correctness of this view. I have noticed considerable variety in appearance in the specimens of hairlike coke, which I have examined under the microscope. This is a subject that deserves investigation by a competent microscopist.

From some accounts of the experiments at the testing plant at St. Louis I understand that few coals are capable of forming the product and that no one seems able to control the conditions that produce it. I tried to get quotations on the product in quantities. One coke manufacturer quoted it at \$20 per ton, but could not guarantee any quantity at that price. The subject, however, deserves further investigation, as there are many industrial uses to which such a material could be put.

EXCELSIOR CHARCOAL AS ELECTRODE.

The use of "coke whiskers" being out of the question on the large, commercial scale, I was forced to have resort to some other form of carbon that would be a substitute. It occurred to me that "excelsior fiber," a substance very generally used for packing and in the upholstering of cheap furniture, might be made into a pervious mass presenting a precipitating surface like zinc shavings.

Ordinary charcoal is practically a nonconductor, but I overcame the difficulty in this regard by heating the charcoal with metallic salts of silver, copper, or lead. I found that such charcoal could be converted into graphite in the electric furnace. Better still, I found that it was not necessary or even desirable to use the electric furnace, or to convert the excelsior entirely into graphite, as charcoal heated to a low orange became an excellent conductor without the addition of any foreign substance whatever. Grass, pine needles, straw, hemp rope, and many other materials also would serve, if coked at a sufficient temperature; but of all of these, excelsior charcoal proved the best. As regards ash content, for example, the excelsior was found to contain only about 1 to 3 per cent, whereas pine needles, for instance, often carry as much as 20 to 30 per cent.

I thus had a suitable material for pervious electrodes that could be used either as anodes or cathodes, or both in alternation. I found

that gold, silver, and copper could be precipitated upon such electrodes just as well as on a sheet of metal, and could be removed by making the charcoal cathode into an anode in a cyanide solution. The deposited metal could then be concentrated from a large cathode surface upon a small one. The most encouraging feature of all was that the charcoal of the anodes dissolved in the solution only at very high voltages, and after the gold and the silver had been removed. The action on the charcoal was much like that on graphite, and the charcoal, notwithstanding the large surface exposed, was less attacked than was hard carbon. Caustic lime seemed to precipitate any dissolved substance occasioning any discoloration; and after aeration, the solution so treated dissolved gold and silver as well as fresh solutions containing the same amount of cyanide would.

THE ELECTRODE SURFACE.

The area of surface exposed by "coke whiskers" and by excelsior charcoal is an important consideration. A cylindrical filament of "coke whiskers," 22 mm. long by 0.078 mm. in diameter and weighing 0.18 mg. has a skin surface, neglecting the area of the ends, of 5.388 square millimeters; therefore 1 gram of fiber represents an area of about 300 square centimeters. Thirteen grams of the material can be packed loosely, without difficulty, in a space of 384 cubic centimeters. Hence a gram occupies 30 cubic centimeters and has 300 square centimeters of precipitating surface.

"Excelsior charcoal" filaments may be produced of any degree of fineness. One average filament that I measured was 25 mm. long, 0.165 mm. thick, and 0.44 mm. broad. Its skin area would be 30.25 square millimeters, or 0.3025 square centimeters, and its weight was 1.6 mg. The surface of excelsior fiber thus may approximate 189 square centimeters per gram. The area for a given weight is then less than two-thirds that of an equal weight of "coke whiskers." Nevertheless "the excelsior charcoal," if made fine, is not so pervious to the solution, and on the whole works extremely well.

A comparison of the surface area of simple pervious electrodes as compared with the compound pervious electrode becomes of importance. When excelsior charcoal is placed in narrow rectangular boxes with cheesecloth sides to form electrodes that may stretch across the deposition box, two forms of construction are possible. If each box has a graphite or other conductor to supply the current we have what may be called a simple pervious electrode. If connected with the plus pole it becomes an anode, if connected with the minus

pole it becomes a cathode. Instead of making use of this arrangement, pervious anodes of another kind may be used. These may be graphite combs, perforated peroxide-of-lead sheets, or the peroxidized lead wire anodes previously described. Any combination of these makes a suitable working system. With the simple pervious cathode, having both sides exposed to an anode, the metal extends downward on both sides and penetrates the charcoal.

The simple pervious electrodes have given excellent results in the precipitation of metals from solutions, but have the disadvantage of requiring many electrical connections, one being required for each anode and for each cathode. As a consequence, whenever an anode or cathode is to be removed there is trouble in establishing and procuring the electrical connections. Constant watchfulness is then necessary to maintain good electrical contacts.

In figure 32 are shown two pervious cathodes, *c*, of the kind described. These may be supposed to be made either of wire cloth or of fragments of coke or graphite, or of "coke whiskers" or excelsior charcoal contained in a suitable box with sides of cheesecloth, and placed between pervious anodes, *a*. It would ordinarily be supposed that the whole of the inner surface of such pervious cathodes would be effective for receiving the precipitate of metal. However, I have found that metal precipitated by the

electric current on such pervious cathodes forms a deposit of only moderate depth. The depth depends on the permeability of the material and increases with the free interstitial space. When granules of graphite, or of coke, one-eighth of an inch in diameter are placed in such frames, the metal deposit extends into the electrode to a depth of about 1 to 3 granules. With wire cloth it penetrates to a greater depth, but in all types, if the thickness of the electrode is great, the interior (marked *o*, fig. 32) receives practically no deposit, while the outer portions, marked with the minus sign (—), become heavily coated. The interior may be said, then, to be in an "electrolytic shadow." Here and in what follows regarding this neutral portion of the pervious electrode, I refer only to the metal that is deposited by the electric current, and not to that deposited by chemical action of the solution on the material of the electrode itself, as sometimes happens. The depth through which the current penetrates and acts on the solution varies from one-eighth to

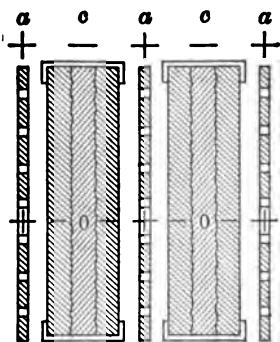


FIGURE 32.—Pervious electrodes. *a*, Anode; *c*, cathode.

one-half inch with the ordinary perviousness. The more compact the particles of the conducting substance, the shallower will be the metallic deposit, until at the extreme, when the perviousness diminishes to that of a sheet of compact metal, the deposit does not penetrate the cathode at all and is deposited on the surface. The discovery of this fact, which from the first appeared to be a disadvantage in the use of pervious cathodes, led me to simplify the pervious electrodes for receiving the deposit of metal. This feature is illustrated in figure 33.

In figure 33 is shown a deposition box, *A*, which is to contain the solution of a metal salt, such as copper sulphate, or cyanide of gold or silver and potassium. At *a'* is shown an insoluble anode of carbon or platinum, and at *c'* a cathode also of carbon or platinum. Now,

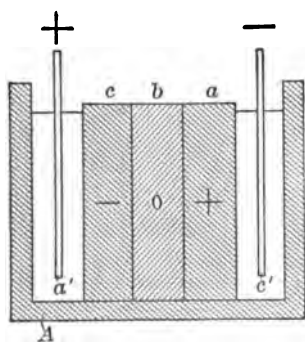


FIGURE 33.—Deposition box with pervious electrode. *a*, Anode (+); *b*, neutral part (0); *c*, cathode; *A*, deposition box.

if there be placed in the solution between these anodes and cathodes a pervious electrode, made either of sheets of wire cloth or a mass of granules of coke, graphite, "coke whiskers" or "excelsior charcoal," and if an electric current be caused to enter the solution at the anode *a'*, and to pass out by the cathode *c'*, the end of the pervious electrode *c* nearest the anode *a'* becomes charged with negative electricity, as indicated by the minus sign, and copper or gold and silver will be deposited upon that side of the pervious electrode to a depth of one-eighth to one-half inch or more, depending upon the perviousness. The oppo-

site side, indicated by the plus sign, of the pervious electrode becomes charged with positive electricity to a similar depth back from the face. The intermediate part, *b*, of the pervious electrode is neither negatively nor positively electrified; and practically no metal will be deposited there. My first improvement consisted in utilizing this idea in the construction of what may be called a compound pervious electrode. One face of this electrode acts as an anode and the other face as a cathode; between these faces is a part acting neither as a cathode nor as an anode, simply conducting the current as a solid metallic conductor would do.

Figure 34 shows the manner in which the compound pervious electrodes are used. Only the electrodes and not the deposition box are shown in this figure. The compound pervious electrodes are marked

e_1 and e_2 . They may be of any number desired. The positive electric current enters the solution by means of a simple pervious anode e , the whole of which becomes charged with positive electricity. At a suitable distance, preferably as small as possible without short-circuiting, is placed the compound pervious electrode marked e_1 . The side c nearest the anode e acts as a cathode and is marked with a minus (—) sign. The middle portion b is neutral and is marked o . The side a acts as an anode and is marked with a plus (+) sign. At a suitable distance is placed a second compound pervious electrode e_2 , and at proper distances as many more of these as may be necessary. Finally a simple pervious cathode e_3 , marked with a minus (—) sign, is provided where the electric current leaves the solution. The manner in which I prefer to arrange such a combination of compound pervious electrodes is shown in figure 35.

In figure 35, at B , is shown a large tank or reservoir containing the solution to be treated, and at A the deposition box. The solution is forced to circulate through the box A by means of the centrifugal pump F , driven by some such means as the motor G . The circulation is from the tank B through the deposition box, and back again repeatedly through pipe g . Also, solution may be drawn from the bottom of the tank and supplied to the tank on a float at the top, so that the poor solution above shall not mix with the rich solution below. It is also possible to circulate the solution from the tank through the box once only, provided the box is made sufficiently long to insure complete precipitation in a single passage; but the method shown in figure 35 is preferable. The electric current enters at the simple pervious anode e , passes through the solution to the compound pervious electrode e_1 , then through the solution again to compound pervious electrode e_2 , and so on to the simple pervious cathode e_3 , by which it leaves the box through the ammeter E . At C is shown a suitable voltmeter for determining the voltage between the terminals of the deposition box A . By the action of the current each of the compound pervious electrodes e_1 , e_2 , etc., receives a metallic deposit on the side that is negatively electrified. The side a , as shown in figure 34, receives no metallic deposit and the part b practically none, unless by the chemical action of the electrode itself, while the side c receives the deposit as a whole. The part marked a being subjected to such action as occurs upon any anode, is liable to be attacked by

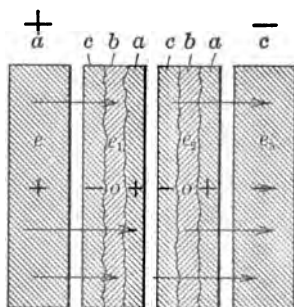


FIGURE 34.—Arrangement for compound electrodes. a , Anode (+); b , neutral part (o); c , cathode (—); e_1 , e_2 , compound pervious electrodes; e , simple pervious anode; e_3 , simple pervious cathode.

the solution unless made of some substance insoluble in the electrolyte.

In cyanide solutions "coke whiskers" and "excelsior charcoal" have been found sufficiently resistant to act as anodes at any ordinary voltage without protection. The aerated solution has the same solvent action upon gold and silver as does a pure solution of the same strength.

Such compound, pervious electrodes may also be termed pervious bipolar electrodes. They have a great advantage over the simple pervious cathodes. Thus a box requiring a potential drop of 2.5 volts with a 110-volt current can be arranged with 40 current gaps—

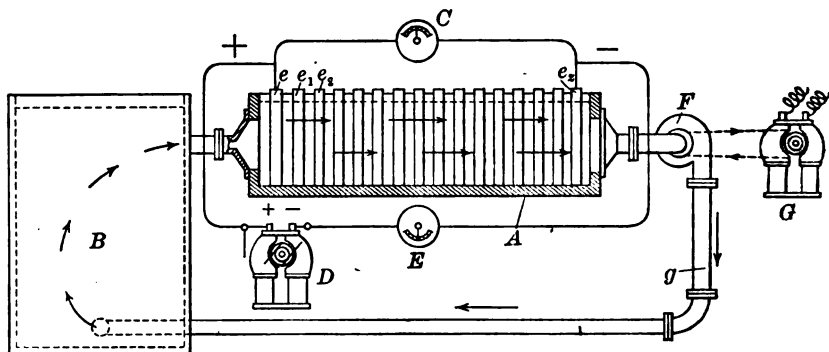


FIGURE 35.—Arrangement of apparatus for use with compound electrodes. *e*, Simple pervious anode; *e*₁ *e*₂, compound pervious cathode, and *e*₃₉, simple pervious cathode. Other letters same as in figure 30.

namely, 1 pervious anode, 39 compound pervious electrodes, and 1 simple pervious cathode. There being only two electric connections to be made, any intervening compound pervious electrode can be removed and replaced as often as convenient without interrupting the current. If the simple pervious cathode at the end is to be removed, an uncharged one can be placed in front of it and connected with the negative pole, when the other can be removed from the circuit. A direct-current service of 220 volts has been used, but I do not recommend so high a voltage, on the whole, on account of the inconvenience to those working at the deposition box. It is, however, easy to protect one's self from shocks by wearing rubber-soled shoes, or, if necessary, rubber gloves. The 110-volt current gives no inconvenience without protection. A patent (U. S. patent 883170, Mar. 31, 1908) was granted me for the electrodes herein described, and further details may be found in the claims there set forth.



APPARATUS FOR ELECTRODEPOSITION OF GOLD AND SILVER FROM CYANIDE SOLUTIONS. CHRISTY PROCESS.

DESCRIPTION OF AN EXPERIMENTAL PLANT.

many readers may desire to verify the statements here made to try the process on their own solutions, details are given here complete small-scale tests. Such tests always should precede large-scale work, for by so doing the essential factors can be foreseen and the necessary size of plant can be accurately determined. The type of plant used by the writer is shown in Plate I.

DEPOSITION BOX.

In the early experiments were made with a box 10 inches in length, which afterwards was increased to 13 inches, as shown in the illustrations, and still later to several feet. The box is 6 inches deep, $4\frac{1}{2}$ inches wide and discharges at a height of $4\frac{1}{2}$ inches. It is illustrated in Plate II, A.

The box is made of redwood 1 inch thick. The end joints are joined in with a tenon and two pieces of string are laid along the joints to bruise the wood, causing it to swell tight when wet. After being dried, the box is immersed in water until it swells tight. It is then taken out and partly dried, after which it is given several coats of a special paint, such as "P & B" paint made from residues of California petroleum dissolved in carbon bisulphide. It is important to apply the paint until the wood has swelled. If painted first, the box can never be made tight. Boxes fitted with circular-saw joints leak less, as a rule, than those with planed joints.

ELECTRODE BOXES.

The electrode boxes are made of strips of soft wood one-half inch thick and three-eighths inch wide. On the bottom is nailed a strip one-eighth inch thick and three-fourths inch wide. These are fastened together, and over the rear side is stretched a piece of cheesecloth, which is drawn tight, overlapping, and fastened to the box with thick "P & B" paint.

The outside dimensions of the frames as constructed are $4\frac{1}{2}$ inches wide by $5\frac{1}{4}$ inches high. The inside dimensions are $3\frac{1}{8}$ inches wide by $4\frac{5}{8}$ inches high. The box is half an inch deep. The inner cross section is practically 16 square inches or 1 square decimeter; that is, one-ninth square foot or 0.01 square meter. For making a new apparatus I should advise an inner cross section of 4 by 4 inches, making exactly one-ninth square foot, or 1 square decimeter, and should modify the dimensions of the deposition box accordingly.

The cover of these boxes is made three-eighths inch wide and one-fourth inch thick. Stretched over the inside and lapped over the outside is a layer of cheesecloth, which is fastened to the frame by a

coat of thick "P & B" paint. The cover is provided with a small pin at the bottom to be inserted in the projecting lip at the bottom of the frame, and is fastened on the top by a simple clamp made of hard rubber. The box, when thus made and assembled, holds approximately 8 to 10 grams of excelsior charcoal in a space 10 by 10 by 1.25 cm. in size. The box should be put together in such a manner that the cheesecloth side of the cover is in direct contact with the charcoal, thus leaving a space of one-fourth inch between the several boxes.

When these boxes are used as compound pervious electrodes they require no further addition, but when it is desired to use them for simple pervious cathodes an aperture of about one-fourth inch through the center of the box at the top is necessary for the introduction of the electrode rod of Acheson graphite. For simple pervious cathodes, however, a wire of iron, silver, or copper may be used, but the graphite rod is preferable. As thus constructed and assembled the box has a thickness of about three-fourths of an inch. Allowing for slight irregularities in construction, it is possible to use 15 of these boxes in a distance of 1 foot in length of the box; and as 1 of these serves as an anode, there are 14 effective compound pervious electrodes in each foot of length of box. Formerly I so made these boxes as to contain a layer of charcoal an inch thick, but found that better results could be obtained by reducing the thickness to one-half inch. Beyond this limit it does not seem to be wise to go. With the compound pervious electrode it is necessary to pack the charcoal as thick as indicated, namely, at least 10 grams to each box, to prevent passage through the charcoal without full chemical action. With two such boxes as I have indicated here—that is, with 28 current gaps—I have employed a voltage of 110.

CIRCULATING PUMP.

In order to give a small, compact precipitation plant, the use of a centrifugal or other circulating pump is necessary. The pump used in the small-scale experiments has been already described. For packing the stuffing boxes I use a little cotton or wool soaked in graphite and vaseline. The whole interior of the pump is painted with "P & B" paint, and where thus protected shows no signs of wear or chemical action. The only part of the pump which is not thus painted is the shaft, which is kept bright by the graphite and vaseline. I use two pumps on the same bedplate in preference to one in order to balance the side thrust.

The deposition box that I have here described has 4.28 liters capacity up to the water line. When filled with 15 electrode boxes with their charcoal content the clear space is about 2.4 liters. If the

compound pervious electrodes are not used, I prefer to use anodes made of Acheson graphite or the wire ones of peroxidized lead. In the small box are four Acheson-graphite rods about three-eighths of an inch in diameter. The upper ends of these are inserted in a graphite bus bar having conical or threaded holes an inch apart, thus giving an anode of comb-shaped form. I have used these graphite anodes repeatedly at 4 volts without signs of disintegration.

With simple pervious anodes I place an anode on either side of a cathode or between each pair of cathodes. With solutions containing sulphates I prefer to use the peroxidized-lead wire anode described on page 100. In this case I use a square frame made of painted wood three-fourths inch wide and one-fourth inch thick. Through this are stretched six lead wires about one-eighth inch in diameter, coated with peroxide of lead in the manner described. The wooden frame is coated with "P & B" paint.

In assembling the apparatus I connect the two suction pipes of the double pump at the opposite sides of the solution tank, preferably from near the bottom, rather than from the top, as in figure 35. The pump discharges through the deposition box, and the solution returns on the float board at the top of the tank, avoiding admixture with the stronger solution below. The circulation is maintained until the gold and silver content of the solution is sufficiently reduced.

I find the unit deposition box that I have described very convenient for use. The length of the box may be increased, if desired, or the same result may be attained by placing one box behind another, in series, until sufficient precipitating surface is obtained. With rich solutions containing much gold and silver, I have had the silver deposit so fast as to clog the filter cloth, a growth of silver having been formed on the outside of the cover, necessitating the removal of this from time to time to clear away the crystals of pure silver. This does not happen with poor solutions. However, as the interstitial space of the electrodes becomes filled with gold and silver, and particularly if the solution is foul with lime and ferrocyanide of potassium, often there is a considerable resistance to the circulation of the solution. There are two remedies for this, one is to reduce the speed of flow and the other to increase the grade of the box. I have frequently in precipitating rich solutions, on this account, inclined the box 1 to $1\frac{1}{2}$ inches to the foot, and have experimented with velocities of flow ranging from 2 to 5 liters per minute in the box of the size indicated. If the actual interstitial space in the box is about $2\frac{1}{2}$ liters, the actual rate of flow through the box would be 1 to 2 feet per minute. Such a rate, however, is not necessary with rich solutions. It will be noted in the foregoing that even greater velocities of flow may be required with dense currents and

low metallic content of solution to obtain rapid precipitation. When, toward the end, the solution becomes much reduced in metal the charcoal becomes choked with hydrogen bubbles, and the grade of the box must be increased or, with a high rate of circulation, the box will overflow.

DISTRIBUTION OF PRECIPITATION IN THE DIFFERENT CELLS.

When simple pervious anodes and cathodes are used, there is a uniform voltage throughout the whole deposition box, and the metal is precipitated on the outer side of each cathode uniformly throughout the box. With compound pervious electrodes a uniform distribution of voltage can be obtained if the charcoal is carefully packed so as not to leave any clear path for the electric current through the solution and not through the charcoal. There is always a tendency for the charcoal to settle in the box, and there is frequently a clear passage for the current along the water line or along the edges of the frame. In order to prevent this, care should be taken in packing the boxes. Moreover, electrode cells may be staggered by wedging them close to alternate sides of the deposition box, although it is preferable to avoid such grooves in a small experimental box, as they complicate cleaning in preliminary tests. In large boxes grooves are, of course, necessary. With proper precautions taken, the fall of voltage is very uniformly distributed throughout the box; but there is nearly always a tendency for the difference of potential between the first two boxes and the last two boxes to be greater than between the others. If the boxes are carelessly packed the difference may be considerable. On this account the first anode in the compound pervious electrode box should be a graphite comb or of peroxidized-lead wires. This distributes the current uniformly across the whole section of the box, and somewhat reduces the resistance.

If the distribution of the voltage throughout the box is uniform and the circulation of the solution through all parts of the box is also uniform, the precipitation of gold and silver will be very uniform. With the compound pervious electrodes the coating of silver seldom is more than one-eighth to three-sixteenths or at most one-fourth inch thick, but there is always a tendency for the simple pervious cathode at the end of the box to become more thoroughly coated than the others, owing to the leakage of current from the upper electrodes. For this reason it is good policy in treating very rich solutions to replace the last simple pervious electrode at the end of the box, as it becomes charged with silver and gold, more frequently than the others. The compound pervious electrodes also should be examined at intervals, and if the metallic precipitate tends

to creep up on the outside of the cover, giving danger of short-circuiting, it is best to remove the covers, replace them with fresh ones, and when convenient remove the silver from the coated covers. If desired the metal-laden charcoal may be replaced continuously, for no harm is done if any one of the compound pervious electrodes is removed from the series and replaced by another with fresh charcoal.

The experimental deposition box shown in Plate II, *A*, I have found most convenient. Boxes *a* and *b* are of the same dimensions and, as has been described, are 13 inches long on the inside and are capable of holding 12 inches of electrodes, allowing three-fourths inch for the distribution of the incoming solution at the head of the box and one-fourth inch for the discharge at the tail end. Box *a* is shown mounted with one form of simple pervious electrodes. There are seven simple pervious cathodes filled with excelsior charcoal and eight simple pervious excelsior-charcoal anodes. Each box is provided with an Acheson-graphite rod for the distribution of the current from the bus bar, the anodes being connected with a positive bus bar, and the cathodes with a negative one. At *c* are shown two of the simple pervious cathodes, one directly beneath the other. The only difference between the simple pervious anodes and the corresponding cathodes in this form of construction lies in the one being connected with the positive current and the other with the negative. At *d* are shown two of the same boxes used as compound pervious electrodes, the difference being that the electrodes *c* are provided with graphite rods for connecting them with the bus bar, whereas electrodes *d* require no such provision. However, as the simple pervious cathode has silver deposited on either side of the cloth, such cathodes are more convenient when made with a rectangular frame for the box one-half inch thick and with two covers one-fourth inch thick, provided with cheesecloth backing, so that the covers may be removed from either face of the electrode for removal of the charcoal. This construction is not absolutely necessary, but it makes the clean-up more convenient.

The box *b* shows the arrangement for a number of compound pervious electrodes and is the form that I prefer for that kind of work. At the head of the box, marked with a plus (+) sign, is shown the Acheson-graphite anode by means of which the positive current is introduced into the solution. This anode, shown at *e*, may be termed the Acheson-graphite comb anode. It consists of a bus bar of Acheson graphite into which are inserted four graphite rods, clamped together by means of graphite screws. The material is entirely of graphite except the little brass cap to which is fastened the copper connecting wire. The advantage of the Acheson-graphite anode is

that it more thoroughly distributes the current over the whole cross section of the box than would excelsior charcoal alone. As has been said, instead of the Acheson-graphite anode the peroxidized-lead wire anode may be used and is preferable if sulphates are present. In any event the intervening compound pervious electrodes *d* remain unchanged.

These boxes are as compact a form of construction as I have been able to devise of this type. In each box the solution is introduced into the box by the centrifugal pump, flows through the pervious electrodes, and out of the box again into the main tank. It will, of course, be understood that the grade of the box as shown in Plate II, *A*, is for convenience in representation. The grade that I prefer to use is about 1 to 1½ inches to the foot.

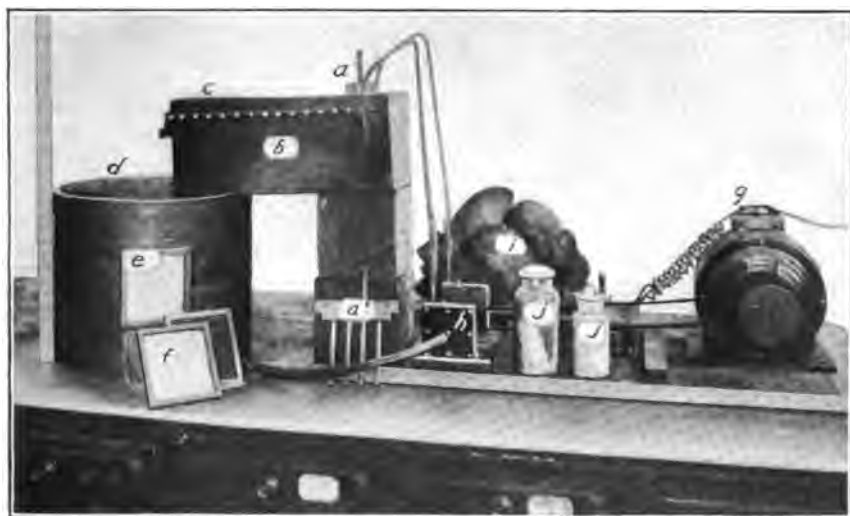
Alternative arrangements are shown in Plate II, *B*. At *a* is shown a very satisfactory form of simple pervious electrode, having seven simple, pervious, Acheson-graphite comb anodes and eight simple, pervious, excelsior-charcoal cathodes similar to *c*, Plate II, *A*, the cathodes being all connected with the negative bus bar and the anodes similarly connected to the positive bus bar.

The simple pervious electrodes shown at *a* in Plate II, *B*, are on the whole preferable to those at *a* in Plate II, *A*, as the anodes of graphite are less acted upon than those of charcoal. The graphite anodes may, of course, be replaced by those of peroxidized-lead wire.

An alternative form of compound pervious electrode is shown at *b* in Plate II, *B*. The current here enters the simple pervious anode marked with a plus (+) sign, passes through the 13 compound pervious excelsior-charcoal electrodes and out through the simple pervious cathode, marked with a minus (—) sign at the lower end of the box. As the simple pervious excelsior-charcoal anode is not so good a conductor as the Acheson-graphite or the peroxidized-lead-wire anode, it does not so evenly distribute the current across the head of the box, and, as stated, I prefer the Acheson-graphite comb anode or the peroxidized-lead wire.

Plate III, *A*, shows the apparatus equipped with the compound pervious electrodes such as was used to handle a 20-liter charge. The box, *b*, is of 4.28 liters capacity, and, with the electrodes, 2.4 liters. The box, together with the tank *d*, holds 22 liters of solution. a convenient charge for an experiment.

The positive current passes to the Acheson-graphite anode *a*, thence through the compound pervious electrodes, not shown, and out through the simple pervious cathode, *c*. The solution overflows from the box into the tank and then passes through the two pumps, *h*, and back again through the box, circulating until the extraction is completed. The motor, *g*, shown here for operating the pump is needlessly large. A compound pervious electrode box ready for use



A. WORKING MODEL. CHRISTY PROCESS.

a, Acheson graphite anode; *b*, deposition box; *c*, simple charcoal cathode; *d*, solution tank; *e*, compound electrode holder; *f*, cover of holder; *g*, motor; *h*, pump; *i*, excelsior charcoal; *j*, bottles of silver residue.



B. BANK OF LAMPS USED FOR RESISTANCE.

compound pervious electrodes I prefer about 5 pounds of charcoal to the cubic foot of cathode space, and for simple pervious electrodes about $2\frac{1}{2}$ to 3 pounds. As I have already stated, the fine charcoal is put at the back or the anode side of the compound pervious electrodes, care being used to fill the box so that no clear space is left for a direct passage of the current. This is particularly necessary with the compound pervious electrodes, the aim being to pack it so that on being held up to the light no light is seen. When so packed the "electrical shadow" or neutral part will also be complete. This leaves 80 to 90 per cent of the interior of the box for solution and deposited metal. The material should be packed a little harder along the edges than in the middle. An inner diaphragm, mentioned in the S. B. Christy patent specifications, I have found unnecessary, provided the charcoal is carefully packed along the edges. A little "P & B" paint at the edges of the cheesecloth prevents electric leakage at these places.

PERMANENCE OF EXCELSIOR CHARCOAL.

If the excelsior charcoal is burned at an orange heat for an hour after the escape of gas ceases it has a steel-blue color, and I find that in this condition it is very little acted upon by the current even when used as an anode. So long as the silver and the gold are contained in the solution the charcoal is acted upon only in the very slightest degree; but after the gold and the silver have been precipitated, particularly if much caustic potash is present in the solution, the charcoal is attacked at a high voltage and slowly imparts to the solution a slight color like that of very weak tea. This coloring matter can be entirely removed from the solution by quicklime, but such removal is not necessary. I have found the action of the solution to be unimpaired if the solution is thoroughly aerated before being used as a solvent for gold or silver.

DETAILS AND RESULTS OF TESTS.

To leave no doubt as to the possibilities of the process I shall go somewhat into detail in certain experiments made by me on various gold and silver bearing solutions. The form of tables which I have adopted I believe to be the briefest and clearest. The conditions as to the circulation of the solution are not always specified, but it should be understood that the rate has usually been 1 foot per minute. In some tests a lower velocity has been found to suffice with solutions very rich in gold and silver, but with an impoverished solution it is well to increase the circulation to the rate specified to attain a satisfactory rate of precipitation.

at *e*. At *f* is the cover of a compound pervious electrode, and this is seen the box itself filled with excelsior charcoal for use. The Acheson-graphite anode is shown at *a*. In the apparatus is a pan filled with excelsior charcoal as it comes from the retort. The two bottles, *jj*, in the foreground contain residues from the clean up and show the material as it is after roasting.

III, *B*, from a photograph taken in the old mining building University of California, shows the means of regulating the current. The laboratory is provided with a 110-volt direct current storage battery or from a dynamo. This current is brought to the laboratory at *a*, the main current passing through the resistances r_1 , r_2 , and r_3 . By connecting with varying points on this resistance, a shunt is formed with any desired voltage for the deposition box. The shunt current passes the ammeter *a* and the small adjustable resistance *r* and through the deposition box and back to the resistance. A voltmeter to terminals of box is shown at *b*. The resistance *r* is used for adjusting the voltage accurately. This means a slight waste of current results in the experiment, it is true, but it is possible to get any voltage needed from 110 volts

The system shown was resorted to after many experiments with special dynamos, storage batteries, and other devices, and eventually one to make use of a 110-volt direct current with no inconvenience. Moreover, by the means shown it is possible to regulate voltage to 0.1 volt and keep it steady all day if necessary. It is necessary only to change the point of application of the shunt or throw in or out a few coils in r_1 or throw in or out a few of the lamps between the resistances r_2 , r_3 , making the final adjustments by the resistance *r*.

Figure IV, *A*, shows in detail the arrangement of a suitable shunt resistance. The frame carries 20 sockets, in which may be inserted in parallel electric-light bulbs of any desired candlepower supplying resistance. These resistances are convenient and they are used generally about the laboratory.

DE OF CHARGING THE BOXES WITH EXCELSIOR CHARCOAL.

The charcoal as it comes from the retorts is in the form of large lump-like masses of closely interlocked fragments. I loosen up the lumps of charcoal carefully so as to reduce the breakage to a minimum and form a mass of homogeneous threads. The material is then carefully charged into the boxes. In order that the charging may be uniform I prefer to counterpoise the box on a weighing scale and to add the charcoal until the required weight is obtained. With

compound pervious electrodes I prefer about 5 pounds of charcoal to the cubic foot of cathode space, and for simple pervious electrodes about $2\frac{1}{2}$ to 3 pounds. As I have already stated, the fine charcoal is put at the back or the anode side of the compound pervious electrodes, care being used to fill the box so that no clear space is left for a direct passage of the current. This is particularly necessary with the compound pervious electrodes, the aim being to pack it so that on being held up to the light no light is seen. When so packed the "electrical shadow" or neutral part will also be complete. This leaves 80 to 90 per cent of the interior of the box for solution and deposited metal. The material should be packed a little harder along the edges than in the middle. An inner diaphragm, mentioned in the S. B. Christy patent specifications, I have found unnecessary, provided the charcoal is carefully packed along the edges. A little "P & B" paint at the edges of the cheesecloth prevents electric leakage at these places.

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The capacity of the boxes containing the charcoal electrodes is not quite so great as of those containing the wire-gauze electrodes. On account of the permanence of the charcoal, however, in first experiments it is better to treat charges of 20 liters at a time until familiar with the manipulations. Results can be obtained then in a single day's work and samples taken in the uninterrupted course of the precipitation. Before large-scale work is begun I should recommend charges of about 500 liters per day, and continuous operation. In this event samples need not be taken so often; perhaps once in four to six hours will suffice. The rise in cyanide content when rich silver ores are being treated will not be as rapid as in the small-scale work, for the reason that the large volume of solution treated requires a longer time for extraction. The rate of increase ought to be inversely proportional to the volume of solution.

In treating ores containing much silver it is not necessary to assay continuously, for if a sample of 1 c. c. of the solution is taken, and to it is added 1 c. c. of dilute sulphuric acid a precipitate of cyanide of silver shows silver to be still present in the solution to the amount of 4 to 5 mg. per 100 c. c. From the density of this precipitate the silver content can be closely estimated by eye. The rate of precipitation, in treating rich silver ores, can also be determined, if the voltage is uniform, by the fall of amperage. So long as the silver is present the current will be high, but as soon as the silver content of the solution falls the current also falls. As regards silver, results plotted on cross-section paper clearly indicate, by the form of the ampere curve, the point where the silver is substantially removed. With gold solutions this does not apply so strictly. The most economical point to stop precipitation is after the cyanide content ceases to increase and begins to decrease. I strongly recommend the plotting on cross-section paper of results obtained in all experiments. Such representation shows the facts in a striking manner and gives a better idea than can be obtained by examining numerals.

TAKING SAMPLES.

For ordinarily rich solutions 100 c. c. portions of solution have been used as samples. The sample is evaporated in a lead boat at a gentle heat with a good but not a strong draft. The evaporation takes place in an hour. The ears of the boat must not be folded tight or capillarity will cause the solution to climb and dry on the sides of the boat, leading to mechanical losses and low results. The dried residue in the boat is sprinkled with a little boracic acid, scorified, cupelled, and parted in the ordinary way. For very low grade gold solutions I prefer to take 603 c. c. of solution for evaporation, and, after scorifying, cupelling, and parting, to weigh the button of

gold in milligrams. Then every milligram represents \$1 in gold per ton of solution, and the amount is obtained directly in dollars and cents. This weight of 603, or more accurately 602.9 grams or approximately 602.9 c. c. of solution, I call the "California gold ton." With low-grade solutions a liter sample may be desired.

I always prefer the evaporation of the solution to any other method in use, as it is absolutely reliable if care is taken to avoid mechanical loss. With 100 c. c. samples results are obtained in about 2 hours. The evaporation method is to be preferred, but the following method of assaying cyanide solutions is satisfactory also, except for solutions very rich in cyanide:

To 100 c. c. of cyanide solution add 6 to 7 c. c. of a 10 per cent lead acetate solution, then add 3 grams of zinc shavings, heat just short of boiling, add 200 c. c. of strong hydrochloric acid, and heat again just below boiling so as not to break up the lead sponge which forms. When the zinc has been nearly dissolved, remove the precipitate of spongy lead, squeeze as dry as possible upon a piece of test lead, dry gently upon the hot plate, wrap with the test lead into the form of a ball and place upon the cupel. The time required to prepare the sample for the cupellation is 15 to 20 minutes. This method, suggested to me by Mr. F. J. Buel, I have found to be particularly satisfactory for solutions poor in gold and silver and not too high in cyanide. When there is a large amount of free cyanide present the results are sometimes low. Where the gold and silver content of the solution is very low and it is difficult to recover the gold bead, which is sometimes very small, it is sometimes an advantage to add 1 c. c. or more of a standard silver nitrate solution before precipitation. The silver nitrate will be precipitated on the lead and add to the size of the bead, preventing loss on cupellation. If desired to estimate the silver, one can deduct the value of the silver nitrate added.

USE OF AMMETERS AND VOLTMETERS.

It is absolutely impossible to do any satisfactory work with electrical precipitation without having constantly in the circuit a reliable ammeter and a voltmeter at the terminals of the cell. It is absolutely necessary to know what amount of current is passing through the solution. When these instruments are used, short circuits are instantly detected by the fall of potential and the rise in amperes, and it is desirable to record these results, as I have done, to know what is happening.

ADVANTAGE OF USING METRIC VALUES.

In investigations of this sort it is important to express results in simple form and to arrange the simultaneous variables in commen-

urate units. The metallurgy of the precious metals has been greatly retarded by the antiquated method of reporting gold and silver in ounces, pennyweights, and grains Troy, with other variables in pounds avoirdupois or in that uncertain unit, the ton, which may mean either the short ton of 2,000, the long ton of 2,240, or the metric ton of 2,204.6 pounds. The American custom of reporting gold in dollars and cents is not much better, for there is always the uncertainty as to whether the silver has been figured at variable current prices, or at one dollar an ounce. The natural difficulties of the problem are numerous enough. No one who has endeavored to correlate work done in Korea, Australia, South Africa, Mexico, South America, and the various American regions can fail to desire the elimination of all complexity possible.

The use of the metric system, estimating large values in metric tons of 1,000 kilograms, and small values in kilograms, grains, or milligrams, has an enormous advantage. Values for volumes and specific gravities are easily converted into definite weights without the uncertainties of the various incommensurate English units. For instance, if gold and silver are reported in milligrams per 100 c. c. of solution, ten times that number gives the number of milligrams per liter (practically per kilogram) and the number is at once the number of grams of gold and silver per metric ton of solution.

If the milligram weight of gold per 100 c. c. is multiplied by \$6.03 we have approximately the assay value of the gold solution per ton in dollars and cents. If the milligram weight per 100 c. c. of either gold or silver be multiplied by 0.29166+, the number of ounces per ton of 2,000 pounds will result. Or, if we multiply by 0.3 we have the approximate number of ounces of metal per ton of solution.

Of these methods of expressing values, the most useful is the expression of grams of gold and silver per metric ton of solution. This method, already widely used in Mexico and in most Spanish-American countries, is much more rational than the one used in this country.

IS COMMERCIAL CHARCOAL SATISFACTORY FOR PERVIOUS ELECTRODES?

In order to settle this point, commercial oak charcoal, used in the laboratory as fuel, was tested with 50 volts. No spark resulted and no current passed as measured by a milliammeter. One piece only that had evidently been overheated showed a trace of a spark at 50 volts. This piece was rejected and the remaining 74 grams was crushed to between 6 and 8 mesh size and filled into a box having cheesecloth sides. This was made a cathode by inserting a graphite rod connected with the negative pole. One graphite comb anode was used. Three liters of a cyanide of silver solution with 0.1 per cent

compound pervious electrodes I prefer about 5 pounds of charcoal to the cubic foot of cathode space, and for simple pervious electrodes about $2\frac{1}{2}$ to 3 pounds. As I have already stated, the fine charcoal is put at the back or the anode side of the compound pervious electrodes, care being used to fill the box so that no clear space is left for direct passage of the current. This is particularly necessary with the compound pervious electrodes, the aim being to pack it so tight on being held up to the light no light is seen. When so packed "electrical shadow" or neutral part will also be complete. This leaves 80 to 90 per cent of the interior of the box for solution and deposited metal. The material should be packed a little less tight along the edges than in the middle. An inner diaphragm, mentioned in the S. B. Christy patent specifications, I have found unnecessary, provided the charcoal is carefully packed along the edges. A "P & B" paint at the edges of the cheesecloth prevents electrical leakage at these places.

PERMANENCE OF EXCELSIOR CHARCOAL.

If the excelsior charcoal is burned at an orange heat for an hour after the escape of gas ceases it has a steel-blue color, and I find in this condition it is very little acted upon by the current even when used as an anode. So long as the silver and the gold are contained in the solution the charcoal is acted upon only in the very slightest degree; but after the gold and the silver have been precipitated, particularly if much caustic potash is present in the solution, the charcoal is attacked at a high voltage and slowly imparts to the solution a slight color like that of very weak tea. This color matter can be entirely removed from the solution by quicklime, but such removal is not necessary. I have found the action of the solution to be unimpaired if the solution is thoroughly aerated before being used as a solvent for gold or silver.

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KCy and 0.1 per cent KHO were then circulated through the box for six hours, with the following results:

Results of test with oak-charcoal cathode.

Time, hours.	Volts.	Ampere.	Silver, mg. per 100 c. c.
0.....	3.5	0.080	126.64
3.....	3.5	.055	119.72
6.....	3.5	.082	106.02

This experiment proved beyond a doubt that such charcoal was practically a nonconductor. The silver did not precipitate on the charcoal, to any perceptible extent, but came down firmly on the graphite conducting rod, and collected slightly between the grains of charcoal. There may have been some chemical action by the charcoal, but none was visible, it came out as black as when it went in. The charcoal not only did not help but actually hindered and acted as would so much nonconducting sand adding to the electric resistance.

RESULTS OF TEST WITH EXCELSIOR CHARCOAL CATHODES.

Three liters of 0.1 per cent KCy solution containing 0.1 per cent KHO, was treated with a single pervious cathode of 10 grams of excelsior charcoal, which had been ignited at a low yellow heat. The solution was not as strong as had been used before, but all other conditions were similar. The results were as follows:

Results of test with excelsior-charcoal cathodes.

Time, hours.	Volts.	Ampere.	KCy content, per cent.	Silver, mg. per 100 c. c.
0.....	3.5	0.275	0.097	74.36
1.....	3.5	.320	.1055	.....
2.....	3.5	.360	.1195	.....
3.....	3.5	.285	.1430	.32
4.....	3.5	.258	.139	.10
6.....	3.5	.249	.111	.06

The precipitation was practically complete in four hours, which is in decided contrast with the results shown of the previous experiment. The high current with the low voltage was due to the high electrical conductivity of the excelsior charcoal.

TO WHAT EXTENT DOES EXCELSIOR CHARCOAL ALONE PRECIPITATE SILVER?

In this experiment 3.3 liters of 0.1 per cent KCy solution, containing 0.1 per cent KHO, were circulated through 14 grams of excelsior

charcoal with no electric current passing. The results were as follows:

Results of test with excelsior-charcoal cathode and no electric current.

Time, hours.	Volt.	Ampere.	KCy content, per cent.	Silver, mg. per 100 c.c.
0	0	0	0.0995	124.40
2	0	0	.0965	122.64
4	0	0	.0945	120.78
5½	0	0	.0935	119.84
9½	0	0	.0935	110.86

The 14 grams of excelsior charcoal had precipitated about 1 per cent of its own weight of silver. The loss of cyanide was small and no regeneration occurred as in the experiment in which electric current was employed.

LOSS OF CYANIDE ON CIRCULATING THE SOLUTION.

Following the previous investigation, experiments were undertaken to ascertain whether a loss of cyanide occurred from circulating the solution with the centrifugal pump. It was found that no such loss took place in the circulating solution when no electric current was passing, provided protective alkali was present, but that with no alkali a slight loss of cyanide occurred in eight hours, evidently due to the presence of carbonic acid from the air.

The cyanide titration each hour gave the following results:

Results of test for cyanide loss from circulation.

	Cyanide, per cent.
Beginning of test.....	0.1
End of first hour.....	.099
End of second hour.....	.0985
End of third hour.....	.0975
End of fourth hour.....	.0965
End of fifth hour.....	.0955
End of sixth hour.....	.0945
End of seventh hour.....	.0935
End of eighth hour.....	.0930

EXPERIMENT ILLUSTRATING USE OF SIMPLE PERVIOUS CATHODES.

An experiment was undertaken to show the recovery of silver and of cyanide of potassium from a rich solution. Only four simple pervious cathodes were used. The current gap was half an inch. The total length of electrodes in the box was 9½ inches, and the

active cross section of the cathodes was 1 square decimeter, or one-ninth square foot, which is the active cross section of the electrodes in the following experiments.

The precipitation in four hours was 92.24 per cent of the silver, whereas the cyanide content increased by 0.090 per cent. A deposition box constructed on the same scale and holding 1 ton of solution, at the same rate, would have treated 36 tons in 24 hours, and would have precipitated 92.24 per cent of the silver.

RECOVERY OF CYANIDE.

The experiment was conducted with four simple pervious cathodes each 1 inch thick, and with a half-inch current gap. The cathodes were of excelsior charcoal and had a total nominal area of 8 square decimeters, or eight-ninths square foot, but the actual surface area, which was incalculable, was much greater. The rate of flow was 2.4 liters per minute. The current density was less than 2 amperes per square foot. The solution was one of KAgCy_2 , and contained 24 grams of silver. The results are shown in the following table:

Results showing the progressive regeneration of cyanide.

Hours.	Volts.	Amperes.	Silver content.		KCy per cent.
			Mg. per 100 c. c.	Ounces per ton.	
0	3.5	2.0	120.15	35.06	0.099
1	3.5	1.9	95.68	27.89	.118
2	3.5	2.15	68.26	19.90	.140
3	3.5	2.32	37.19	10.85	.168
4	3.5	2.25	9.48	2.77	.188
5	3.5	2.2	1.15	.34	.182
6	3.5	2.05	.08	.02	.170
7	3.5	2.00	.02	.006	.154

The preceding table shows that the most economical point at which to stop the precipitation was reached in four hours, for at that time, with only four cathodes, 92.24 per cent of the silver was precipitated and the cyanide had increased from 0.099 per cent to 0.188 per cent, or about 90 per cent. The amount treated was 20 liters, or 6 times the volume of the box, giving a capacity of 26 tons per 24 hours for a 1-ton box. A further analysis of the results of the above experiment is shown in the following table:

Analysis of results of experiment with simple pervious cathodes.

Time, hours.	Volume of solution treated, liters.	Silver deposited.		Average ampere-hours.	Theoretical weight of silver deposited, grams.	Ampere hour efficiency, per cent.	KCy, per cent.	KCy, gain or loss.	
		Mg. per liter.	Grams.					Hourly, grams.	Total gain or loss, grams.
1	19.79	244.7	4.843	1.95	7.868	61.53	+0.019	+3.79	+17.88
2	19.68	274.2	5.369	2.005	8.070	66.70	+ .022	+4.33	
3	19.57	310.7	6.061	2.235	9.018	66.73	+ .028	+5.48	
4	19.46	277.1	5.391	2.285	9.220	57.58	+ .020	+4.28	
5	19.35	83.3	1.612	2.225	8.978	17.95	— .006	—1.16	— 6.53
6	19.24	10.7	.206	2.125	8.574	2.40	— .012	—2.31	
7	19.13	.6	.011	2.025	8.171	.13	— .016	—3.06	

The preceding table shows that the ampere-hour efficiency is high for the first four hours, and that if the action had been stopped 92.24 per cent of the silver would have been recovered. The efficiency of silver deposition was still fair in the fifth hour. For the entire seven hours the silver precipitation was 99.98 per cent. The last two or three hours are seen to have been wasteful of the electric current. The increase in current at constant voltage is probably brought about

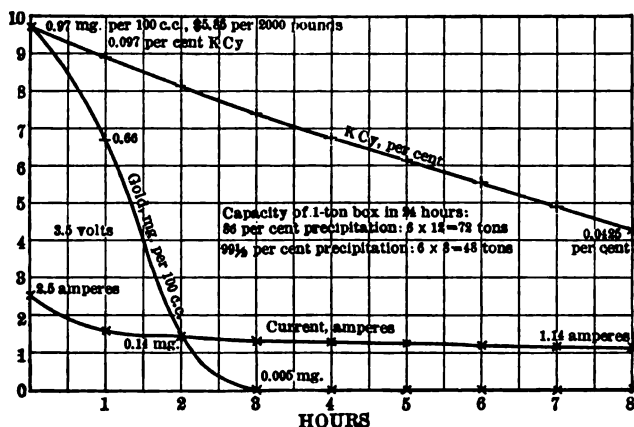


FIGURE 36.—Electrodeposition results with moderately rich gold solution; 4 simple pervious cathodes, each 1 inch thick and containing 14 grams "excelsior" charcoal, and 5 Acheson-graphite comb anodes, each with 4 4-inch rods. Length of box occupied, 9½ inches, cross section 1 square decimeter, 8 cathode faces. Voltage, 3½, ½-inch current gap. Solution, 20 liters, contained 20 grams KCy, 20 grams KHO, 194 mg. Au as KAuCy₃. Rate of flow, 3 liters per minute. Compare with fig. 37.

by increased conductivity of the charcoal due to the deposited metal on it, and the final fall marks the point when the silver was nearly all deposited from solution.

TREATMENT OF A GOLD CYANIDE SOLUTION OF MODERATE RICHNESS.

An experiment was conducted with gold cyanide solution instead of silver cyanide solution, but all other conditions were identical

with the preceding one. The original content of the solution was \$5.85 in gold a ton. The results are shown in figure 36 and in the following table:

Results of experiment with gold solution.

Hours.	Volts.	Amperes.	Gold, milli-grams per 100 c. c.	Gold per ton.	KCy, per cent.
0	3.5	2.5	0.97	\$5.85	0.097
1	3.5	1.6	.66	4.02	.089
2	3.5	1.47	.14	.84	.081
3	3.5	1.38	.005	.03	.0735
4	3.5	1.29	Trace.	Trace.	.0675
5	3.5	1.25	Trace.	Trace.	.061
6	3.5	1.19	Trace.	Trace.	.0545
7	3.5	1.18	Trace.	Trace.	.0485
8	3.5	1.14	Trace.	Trace.	.0425

Evidently there was no advantage in continuing after the first three hours, as 3-cent tailings are sufficiently low. While a regeneration of cyanide is possible from rich silver solutions, it is not usually possible with such gold solutions as occur in practice. A steady loss

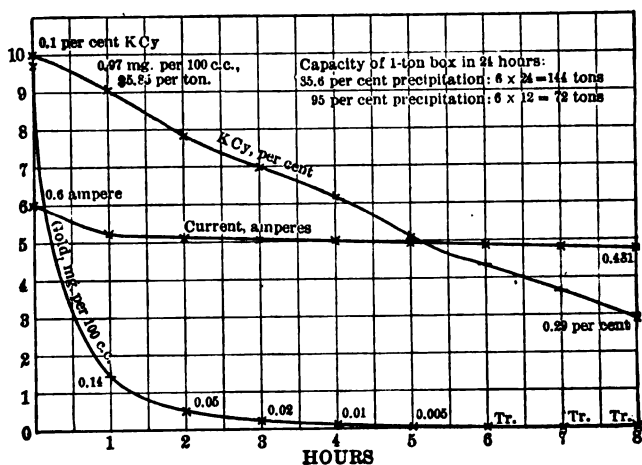


FIGURE 37.—Electrodeposition results with moderately rich gold solution; six compound pervious electrodes, each 1 inch thick and containing 14 grams "excelsior" charcoal, and 1 Acheson-graphite anode. Length of electrodes, 9½ inches; six cathode faces; six ¼-inch current gap at 3.5 volts, 21 volts in all. Solution and rate of flow, same as in fig. 36.

of cyanide occurs with these, nearly proportional to the time, but increasing somewhat with the decrease of gold.

EXPERIMENT WITH USE OF COMPOUND PERVIOUS ELECTRODES.

A duplicate of the preceding experiment in all conditions other than that compound pervious electrodes were employed was next conducted. (See fig. 37; compare with fig. 36.) The five compound

pervious cathodes were each 1 inch thick. The length of the electrodes in the box was $9\frac{1}{2}$ inches. In this experiment there were only six cathode faces instead of eight, as before. The current gap was one-half inch. The six current gaps at $3\frac{1}{2}$ volts amounted to 21 volts. In three hours 98 per cent and in four hours 99 per cent of the gold was precipitated at a capacity of 24 tons per 24 hours in a 1-ton box.

RECOVERY OF SILVER AND REGENERATION OF CYANIDE.

A similar experiment was further undertaken to illustrate the recovery of silver and also the recovery of cyanide. In the experiment six compound pervious electrodes were used, each 1 inch thick and containing 14 grams of charcoal, and one simple pervious Acheson-graphite anode. The six current gaps were one-half inch each. The length of box was $9\frac{1}{2}$ inches, and the solution was 20 liters in volume, containing 20 grams KCy, 20 grams KHO, and silver in the form of KAgCy_2 . The results were as follows:

Results of experiment to show recovery of silver and cyanide regeneration.

Hours.	Volts.	Ampere.	Silver.		KCy, Per cent.
			Milligrams per 100 c. c.	Ounces per ton.	
0.....	21	0.730	125.29	36.6	0.0985
1.....	21	.709	86.97	25.37	.1240
2.....	21	.691	44.86	13.01	.1570
3.....	21	.622	16.21	4.72	.1795
4.....	21	.560	1.68	.48	.1830
Added KAgCy ₂	21	.820	126.95	37.00	.....
5.....	21	.820	79.60	23.21	.219
6.....	21	.813	30.36	8.85	.252
7.....	21	.759	5.38	1.57	.251
8.....	21	.740	.38	.11	.236

The table shows that during the first four hours there was recovered 98.69 per cent of the silver from the 36.6 ounces present and 0.0845 per cent of the KCy, not allowing for samples. During the second four hours 99.7 per cent of the silver was recovered from the 37 ounces present, and 0.053 per cent of the KCy.

EFFECT OF CURRENT GAP.

Some experiments were undertaken to determine the effect of current gap upon capacity. In these tests the electrodes were one-half inch thick and were filled with excelsior charcoal. In the experiment in which, for example, the current gap was one-half inch, each box was one-half inch thick, being filled with charcoal filaments, and had on the outside a one-fourth inch cover, in such a way that two of these one-fourth inch covers were face to face, making a

current gap of one-half inch. The maximum capacity for a 93.5 per cent precipitation with one-half inch current gaps was found to be only 48 tons for a 1-ton box in 24 hours. With the one-fourth inch current gap the maximum capacity for 95.8 per cent precipitation was 144 tons, or nearly three times as great. The length of electrodes in these experiments was $9\frac{1}{2}$ inches. There were in the first experiment eight current gaps of one-half inch at $3\frac{1}{2}$ volts, making a total of 28 volts. In the second experiment there were 11 current gaps of one-fourth inch each at $3\frac{1}{2}$ volts, making a total of 38 volts.

The results of the two experiments, for which curves of precipitation are shown in figures 38 and 39, are well worth careful study and comparison. I strongly advise that the attempt be made to use the smaller current gap wherever it is possible to do so.

EFFECT OF LIME ON SILVER PRECIPITATION.

An experiment was conducted to determine the effects of lime on the precipitation, the solution containing cyanide of silver and free KCy. Compound pervious electrodes were used and one simple pervious Acheson-graphite comb anode. There were 11 cells, each one-half inch thick, and 11 one-quarter-inch current gaps of $3\frac{1}{2}$ volts each, giving $38\frac{1}{2}$ volts for the 11 boxes. The 20 liters of solution contained 20 grams of KCy, and 10.2 grams of CaO, together with 24.43 grams of silver as KAgCy₂. No caustic soda or potassa was present. The precipitation was 93.5 per cent complete at the rate of 144 tons per 1-ton box for 24 hours, and 99.5 per cent complete at the rate of 72 tons per 1-ton box in 24 hours. The results are shown in figure 40.

It is evident from the fall in the content of protective alkali that the caustic lime was partly converted into cyanide of calcium. It was noticed, further, that the fall in protective alkali was coincident with the rise in free cyanide, and that when the silver cyanide ceased to be precipitated the protective alkali remained nearly constant. When a new charge of cyanide of silver was added the protective alkali again fell and the free cyanide increased. The regeneration of free cyanide, in short, was at the expense of the protective alkali. These results are shown by the curves in figure 40. No remark need be made other than that needed to call attention to the rate of precipitation, which was 93.5 per cent in one hour, whereas the capacity was at the rate of 144 tons a day. Furthermore, at the rate of 72 tons a day, 99.5 per cent precipitation was obtained.

SIMPLE PERVIOUS CATHODES WITH SILVER CYANIDE AND LIME.

A test was made in which there were employed six simple pervious charcoal cathodes and six simple pervious Acheson-graphite comb

anodes as electrodes; 20 liters of solution containing 20 grams KCy , 9.52 grams CaO or 0.476 per cent CaO , 38.714 grams silver in the form of KAgCy_2 , and current gaps of one-fourth inch and a voltage

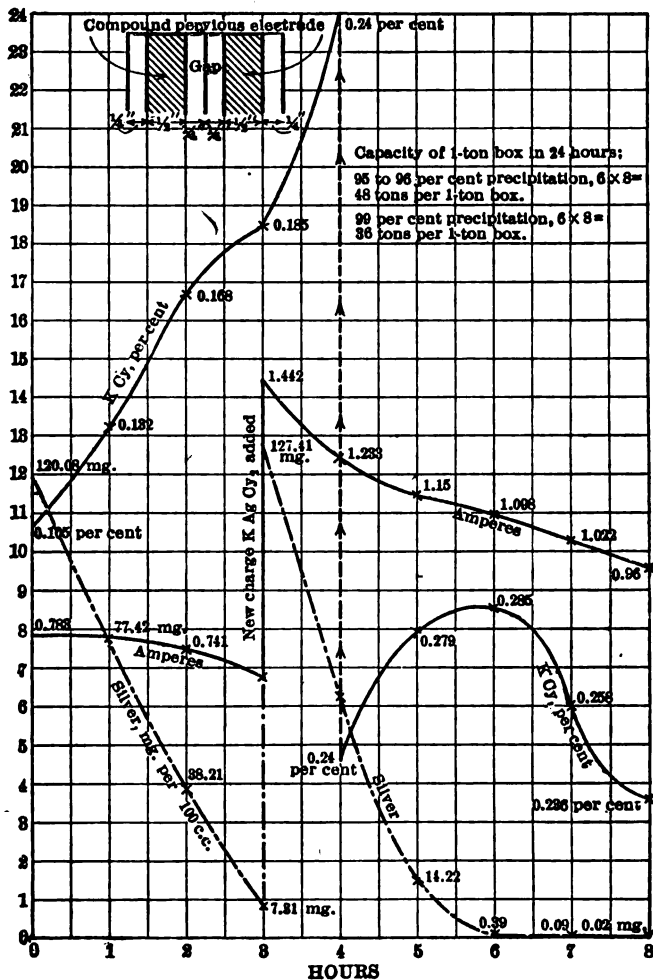


FIGURE 38.—Electrodeposition results with rich silver solution, using $\frac{1}{4}$ -inch current gaps. Eight compound pervious charcoal electrodes, each one-half inch thick; length of box occupied, $9\frac{1}{2}$ inches; cross section, 1 square decimeter. Eight current gaps at $3\frac{1}{2}$ volts, 28 volts in all. One Acheson-graphite comb anode. Solution, 20 liters, contained 20 grams KCy , 20 grams KHO , and 24.016 grams Ag as KAgCy_2 . Rate of flow not recorded; high. Note gain in KC_2 while Ag is being precipitated; loss afterwards

of $3\frac{1}{2}$. The cross section of the box containing the electrodes was 1 square decimeter, and the total length was $9\frac{1}{2}$ inches.

On plotting the results it was found that the amount of silver in solution closely followed the protective alkalinity. Thus as the

silver is removed the content of protective alkali diminishes, while at the same time the free cyanide increases. Certain irreg-

ularities in the conditions of test, due to the lack of sufficient free cyanide of potassium to keep in solution all the silver cyanide that was deposited on the anodes, caused resistances that made the current irregular. The blowing out of a fuse also caused some irregularity, and it is probable that there was some variation in the amperes, due in part to short circuits. However, the precipitation from the rich solution, notwithstanding these irregularities, was found to be very satisfactory.

In four hours the precipitation was 99.74 per cent, the capacity being at the rate of 36 tons for a 1-ton box in 24 hours. For a three-hour period the precipitation was 92.85 per cent, the capacity being at the rate of 48 tons per day for a 1-ton box.

The solution employed was probably as rich as would ever have to be precipitated in practice. Each of the six electrode boxes held 4.66 grams of excelsior charcoal, or 28 grams in all. The ash from this charcoal, including the silver, the lime, etc., weighed 47.59 grams. After the soluble salts were removed with dilute hydrochloric acid the residue—silver and insoluble silica—weighed 39.35 grams as against 38.714 grams of silver contained in the original solution. Hence there was soluble in hydrochloric acid 8.24 grams of substance, in-

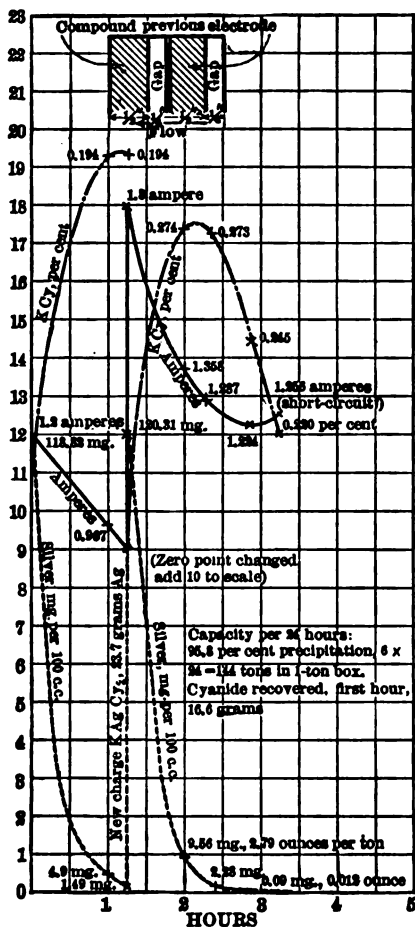


FIGURE 39.—Electrodeposition results with rich silver solution, using $\frac{1}{2}$ -inch current gaps. One Acheson-graphite anode, 10 compound pervious charcoal electrodes, $9\frac{1}{2}$ inches long; cross section, 1 square decimeter; 1 simple pervious charcoal cathode. Eleven current gaps, at $8\frac{1}{2}$ volts, or $88\frac{1}{2}$ volts in all. Solution, 20 liters, contained 20 grams KCy, 20 grams KHO, 23.7 grams Ag as KAgCy₂, and no lime. Electrodes choked with silver; grade increased from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches per foot; rate of flow cut from 3.5 to 0.2 liters per minute (210 to 150 per hour); velocity, 13.8 to 7.9 inches per minute. Note increase in capacity compared with fig. 38.

cluding the hydrates and carbonates of lime and potassa and the soluble constituents of the ash.

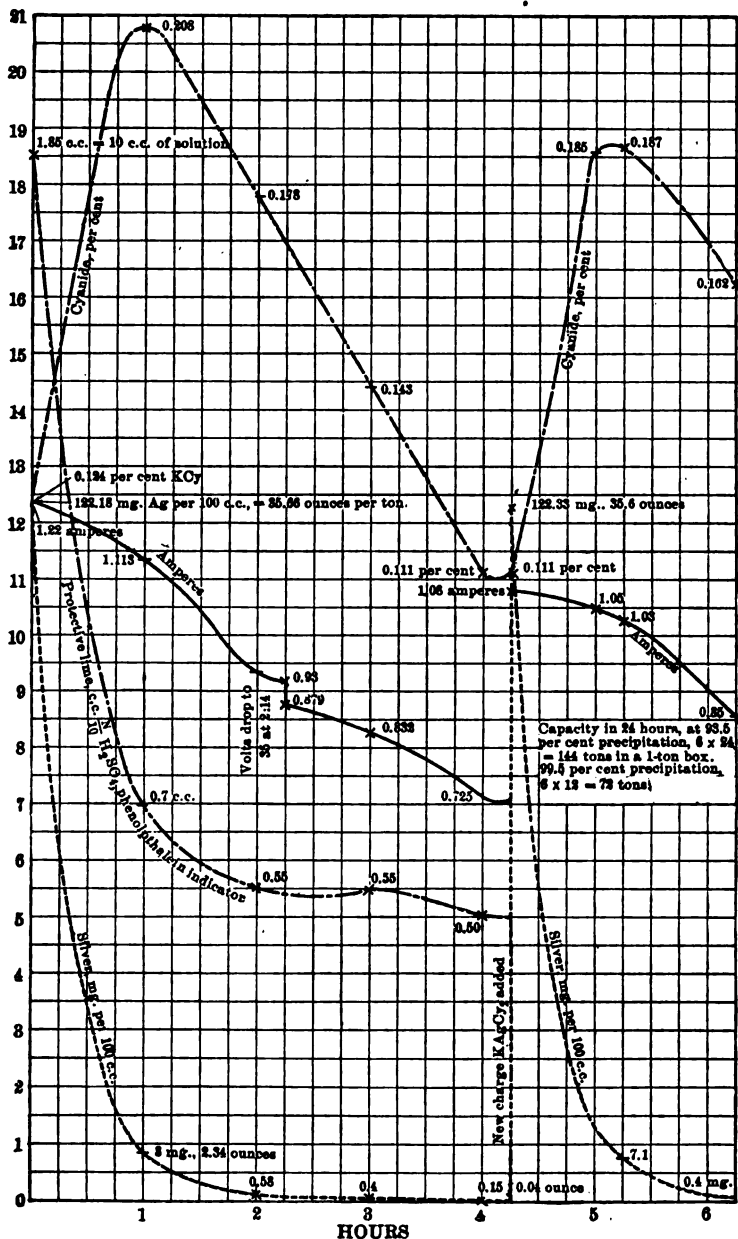


FIGURE 40.—Electrodeposition results showing effect of lime on the precipitation. One simple and 10 compound peroxide electrodes, each one-half inch thick and containing 9½ grams charcoal, 104 grams in all. Eleven one-fourth-inch current gaps at 3½ volts, 38½ volts in all. Solution, 20 liters, contained 20 grams KCy, 10.2 grams (0.051 per cent) CaO, and 24.43 grams of silver as KAgCy; 24.43 grams of silver as KAgCy, was added at 4½ hours; no NaHO used. Rate of flow, 5 liters per minute; velocity, about 18.7 inches per minute.

PRECIPITATION OF GOLD FOLLOWING THE PRECIPITATION OF SILVER.

An interesting experiment was made in which two successive charges, the first of silver cyanide and the second of gold cyanide, were treated in the same box. The electrodes were already coated with silver and therefore were in excellent condition for conducting the current and depositing the gold, which was added from a cyanide solution containing \$24.36 per ton. In one hour 98.27 per cent of the gold was precipitated, the capacity for a 1-ton box being at the rate of 112 tons per 24 hours. The results are shown in Plate V.

It is evident from the precipitation curves that no good purpose was served in continuing the precipitation more than two hours, for when this was done cyanide was lost and little gold precipitated. The precipitation curves are found to be all logarithmic ones, and the precipitation extremely rapid at first, but slow toward the last. The economical period of the precipitation is therefore the first few hours, and this factor should be made use of to the fullest extent possible.

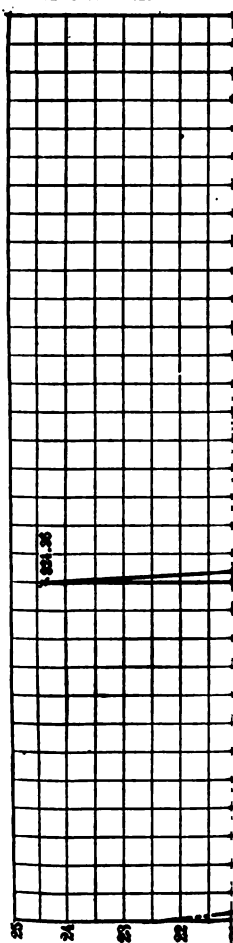
In conducting the experiment one simple pervious charcoal anode with graphite rod was used and 13 compound pervious electrodes, each containing 10 grams of excelsior charcoal. A cathode of the simple-pervious type containing 8 grams of excelsior charcoal was used. There were 14 current gaps, each one-fourth inch. The voltage between electrodes was $3\frac{1}{2}$ and the total voltage 49. The electrodes were 1 square decimeter in area and the length of the box 13 inches. The solution, 20 liters in volume, contained 20 grams NaHO, 20 grams KCy, 24.07 grams silver as KAgCy₂. The rate of flow was 13.8 inches per minute.

At the end of one hour 87.2 per cent of the silver was precipitated. Hence the capacity of the box for a 1-hour treatment is 4.67 times 24, or 112 tons for a 1-ton box in 24 hours. In 1 hour and 30 minutes there was 98.70 per cent precipitated; the capacity was 4.67 times 18 or 84 tons for a 1-ton box. In two hours 99.78 per cent was precipitated, hence the capacity for a 2-hour treatment was 4.67 times 12, or 56 tons for a 1-ton box.

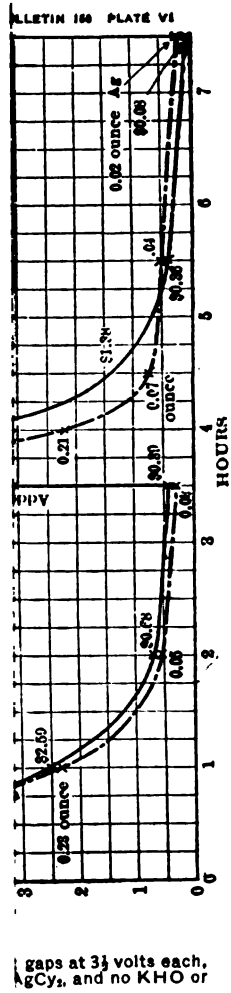
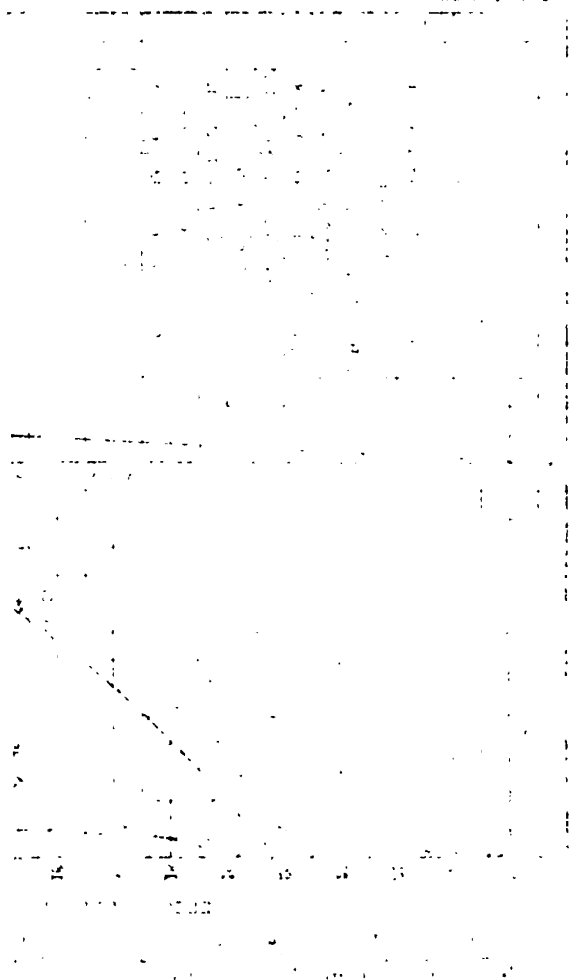
At the end of this experiment 0.808 gram of gold in the form of KAuCy₂ and 0.685 gram of silver as KAgCy₂ were added to the solution without removing the electrodes and the current was started as before. The remarkably good results shown for gold are probably due to the fact that the cathodes were already coated thoroughly with metallic silver, which made them an excellent conductor and facilitated the precipitation of the gold.

In the first hour there was precipitated 98.27 per cent of all the gold present. Hence the capacity of the box, which contains 4.28

BUREAU OF MINES



One Acheson graphite
decimeter. Fourte
tained 20 grams K



iters, would be 4.67 times 24, or 112.08, tons for a 1-ton box in 24 hours. At the end of the first two hours 99.75 per cent of the gold was precipitated, making the capacity of the box equal to 4.67 times 2, or 56.04, tons for a 1-ton box in 24 hours. It will be noticed that here was no advantage in running after the first two hours, as the amount of gold left at the end of that time was only 6 cents per ton. This content was reduced in the full three hours to $1\frac{1}{4}$ cents, but it was accomplished at the cost of destroying the total remaining cyanide. The desirable point at which to stop the precipitation is thus seen to have been probably after the first or second hour.

THE DIRECT USE OF A 110-VOLT CIRCUIT.

An experiment was undertaken to illustrate a mode of utilizing a 110-volt circuit, in which, for the purpose, two 13-inch boxes such as I have described were placed in series. These were given, in the first part of the experiment, a total tension of 98 volts, having altogether 28 current gaps at $3\frac{1}{2}$ volts each. The result, as regards precipitation, was very satisfactory. During the first half hour there was precipitated 93 per cent of the silver, giving a capacity of 112 tons for a 1-ton box. At the end of the first hour 99.8 per cent was precipitated.

The positive current was introduced by a simple pervious anode. Its course was through 13 compound pervious electrodes, out through a simple pervious cathode to a simple pervious anode at the head of the second box, and thence through 13 compound pervious electrodes to a simple pervious cathode. To adjust the voltage a resistance similar to that shown in Plate IV, A, containing twenty 32-candlepower incandescent lamps connected in parallel, was put in series with the cells. As there were 28 current gaps in the two boxes at 3.5 volts, the total voltage was 98 volts.

In starting the experiment, all of the twenty 32-candlepower lamps, connected in parallel, were placed in series behind the box. This gave at the start 98 volts. First one and then a second of these lamps, and so on, were disconnected, to adjust the voltage and to produce the effect wanted. The total length of electrodes in the two boxes was 24 inches; the current gaps were each one-fourth inch. Twenty liters of solution, containing 20 grams KCy and 20 of KHO, was used. The results are shown in figure 41.

In the first half hour, at 98 volts, 93 per cent of the silver was precipitated, the capacity being equivalent to 112 tons for a 1-ton box for 24 hours. At the end of the first hour, at 98 volts, 99.8 per cent was precipitated, the corresponding capacity being 56 tons for a 1-ton box in 24 hours. During the second hour, at 60 volts, 98 per cent was precipitated, and the capacity would be 56 tons for a 1-ton box. The

rate of precipitation, however, had nearly reached the maximum, with the 60-volt charge, at the end of the fourth hour, then fell slightly below 96 per cent in one hour, but at the end of the sixth hour was 99.85 per cent.

PRECIPITATION OF RICH GOLD AND SILVER SOLUTIONS IN THE PRESENCE OF LIME.

An experiment was undertaken to determine the effect of caustic lime (CaO) on the precipitation both of gold and silver from strong cyanide solutions. The results are shown in Plate VI.

The solution contained about $1\frac{1}{4}$ ounces of gold and 1 ounce of silver. A single box with 14 one-fourth inch current gaps was used. The results are to be compared with those shown in figure 41, where the precipitation was more rapid on account of the electrodes having been previously coated with silver and on account of the absence of lime.

In treating such rich solutions there is no necessity of reducing the gold content much lower than 90 per cent, as the solution is used over and over again. The presence of a small amount of gold in the leaching solution has no bad effect on the extraction. The most economical results are obtained in that way. A careful examination of the curves shows the point at which to stop in any given experiment.

The 13-inch box contained 1 simple pervious anode, 13 compound pervious electrodes, and 1 simple pervious cathode. Each of the 15 electrode boxes contained 10 grams of excelsior charcoal. The total length of electrodes was 12 inches, the cross section being 1 square decimeter, or one-ninth square foot. The 14 current gaps, of one-fourth inch each, at 3.5 volts, required 49 volts. Twenty liters of solution were treated, containing 40 grams of KC_y , 0.808 gram of gold as KAuCy_2 , 0.636 gram of silver as KAgCy_2 , and 10.92 grams of CaO .

During the first hour 89.4 per cent of the gold was precipitated, in which time the box treated 4.67 times its content of solution, making the capacity equivalent to 112 tons in 24 hours for a 1-ton box. During the second hour 97.3 per cent of the gold was precipitated, giving a corresponding capacity of 56 tons. At the end of three and one-half hours 98.4 per cent of the gold was precipitated, the capacity corresponding to this rate being 36.5 tons. The second charge was treated four hours, in which time the gold precipitation was 99.5 per cent. The corresponding capacity of a 1-ton box would be 28 tons of solution in 24 hours.

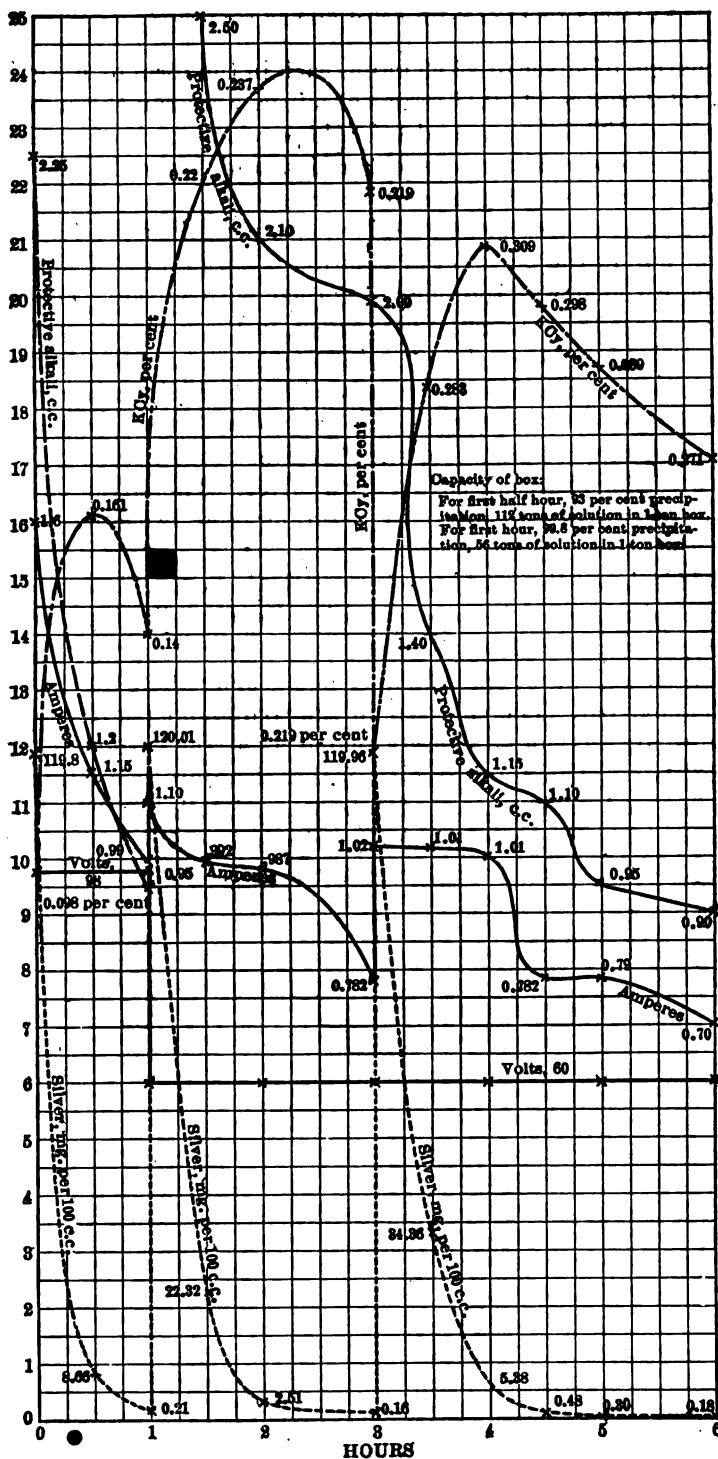


FIGURE 41.—Electrodeposition results with 110-volt direct-current circuit as source of power. Two electrode boxes in series, each having 1 simple previous anode and 18 compound previous and 1 simple previous cathode. Voltage regulated by bank of lamps. Twenty-eight current gaps: mean current drop from box to box for first hour, $98 \div 28 = 3.5$ volts; for rest of test $60 \div 28 = 2.22$ volts. Silver solution, 20 liters, contained 20 grams KCy and 20 grams KHO. Rate of flow not recorded.

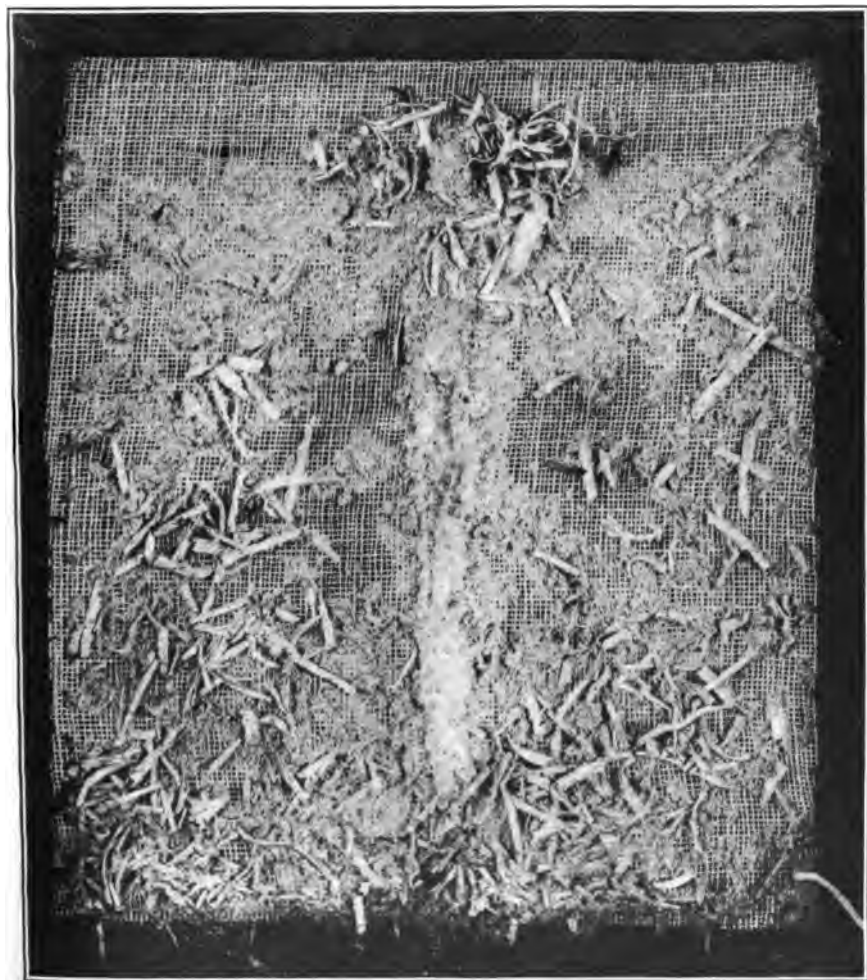
EXAMPLE OF CLEAN-UP FROM SILVER SOLUTIONS.

Three charges of silver of 23.59 grams each in the form of $KAgCy_3$, making a total charge of 70.77 grams of silver, were run through the deposition box. There were used 1 simple pervious anode of excelsior charcoal, 13 compound pervious electrodes, and 1 simple pervious cathode, each containing 8 grams of charcoal.

The solution after treatment contained 0.68 mg. silver per 100 c. c., there being left in the 20 liters of solution 0.126 grams. The charcoal of the cathode was thoroughly gorged with silver. The upstream or cover side of the cathode is shown in Plate IV, *B* (p. 143), the cheesecloth being covered with a mass of pure crystals of silver. The deposit had so extended that there was danger of short-circuiting.

Plate VII shows the reverse side of this cover. Here the cheesecloth is seen to support a mass of silver crystals, together with fragments of excelsior charcoal, coated with silver. The silver on this cover was very easily removed by scraping and brushing under water.

Plate VIII shows the interior of the cathode box. The graphite conducting rod is seen to be covered with a loosely adhering coating of silver crystals. The charcoal in the box is seen to be thoroughly coated with silver, the weight of silver being more than three times that of the charcoal. The charcoal in the compound pervious electrodes, as usual, was not so densely plated as at the cathode at the end of the box. The total result of the clean-up, consisting of 70.644 grams and 4.956 grams of ash, was as follows: From the simple anode, 25.3 grams; from the 14 compound pervious electrodes, cathode side, 46.2 grams; from the 14 anode sides, 4.1 grams.



BACK OF COVER. SIMPLE PERVIOUS CATHODE NEARLY CHOKED WITH SILVER.



SIMPLE PERVIOUS CATHODE USED AT END OF COMPOUND PERVIOUS ELECTRODE; 25.3 GRAMS OF SILVER DEPOSITED ON 8-GRAM MASS OF EXCELSIOR CHARCOAL.

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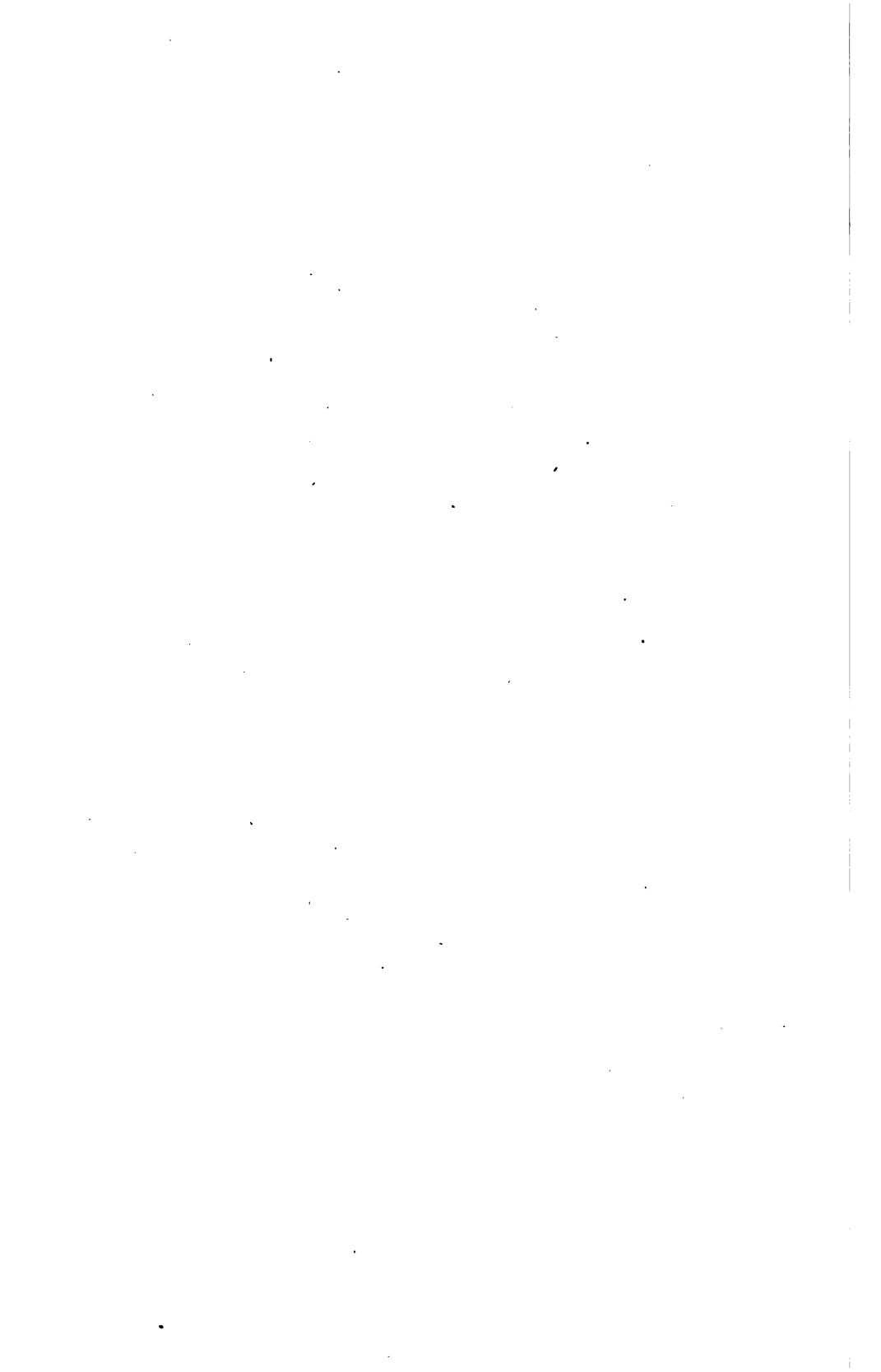
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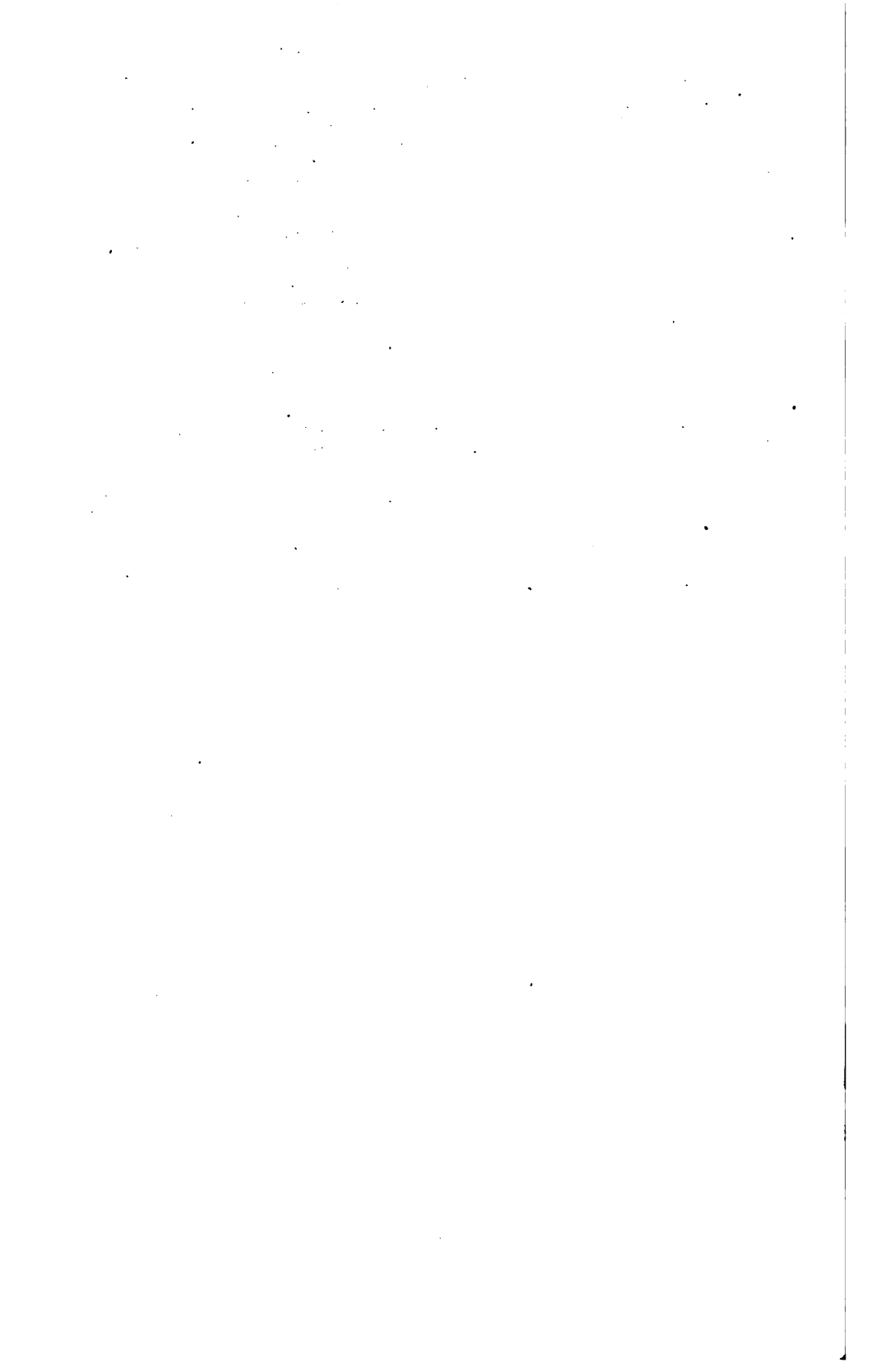
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DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

RECOVERY OF GASOLINE
FROM NATURAL GAS BY COMPRESSION
AND REFRIGERATION

BY

W. P. DYKEMA



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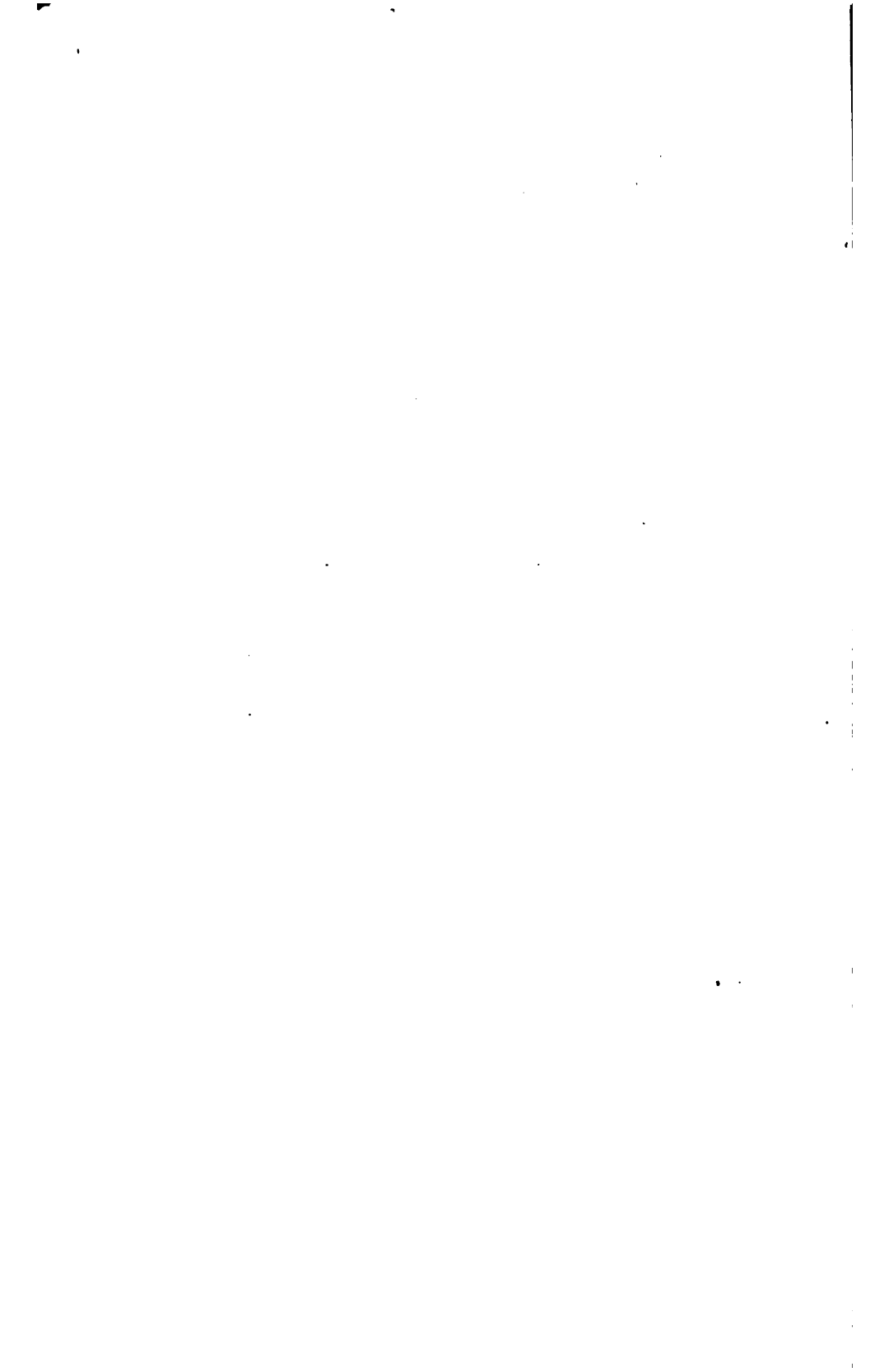
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RECOVERY OF GASOLINE FROM NATURAL GAS BY COMPRESSION AND REFRIGERATION.

By W. P. DYKEMA.

INTRODUCTION.

In investigating the general problems that relate to the petroleum industry in the United States, the Bureau of Mines has given considerable attention to the recovery of motor fuel from natural gas. Recent developments in gasoline power units and their increasing use have made it imperative that all fractions of petroleum suitable for fuel in this type of engine be conserved. The bureau has issued a number of publications on this subject. Among these are Technical Paper 10, "Liquefield products of natural gas, their properties and uses"; Bulletin 42, "The sampling and examination of mine gases and natural gas"; Technical Paper 87, "Methods of testing natural gas for gasoline content"; Bulletin 120, "Extraction of gasoline from natural gas by the absorption method"; and Bulletin 88, "The condensation of gasoline from natural gas."

This report treats of the compression and refrigeration process for the recovery of gasoline from natural gas from the viewpoint of the practical engineer and business man. Conditions of actual operation and the equipment in use are cited and described so that operators, and others interested, can compare the variations in methods of treating natural gas for its gasoline content in the different fields and also the conditions encountered and the features that control the methods used.

ACKNOWLEDGMENTS.

The writer heartily acknowledges the valuable assistance and cooperation of the many plant operators and gasoline producers who have cheerfully furnished data on their plants and granted the privilege of plant inspection.

Particular thanks are due to Messrs. W. R. Hamilton, G. L. Goodwin, and D. L. Newton for the many courtesies extended the writer and for much of the information regarding cooling by expanded gas as practiced in the California fields.

Thanks are also due Messrs. W. P. Donovan, Thomas Chestnut, J. C. Gillespie, A. W. Peake, and R. E. Downing for valuable information on practices in the Mid-Continent fields.

HISTORY OF THE INDUSTRY.

The early history of the manufacture of natural-gas gasoline has been published by the Bureau of Mines ^a in previous papers on the subject. The present practice is the result of the advance developed by a study of the needs of the industry, by improvements in machinery and equipment, and by a better understanding of the thermodynamic and other physical principles involved. A very small proportion of the plants erected have been commercial failures, and most of those which have failed lacked capital to carry them over a period of low prices for gasoline. Many of these plants are still operating, the company having been reorganized or bought up by larger corporations, and under present market conditions they show satisfactory returns.

The following table shows the distribution of casing-head gasoline plants and the amount and value of the gasoline produced in the United States in 1915:

TABLE 1.—Gasoline recovered from natural gas and sold in 1915.^a

State.	Number of plants.	Quantity.	Value.	Average recovery of gasoline per 1,000 cubic feet.
		Gallons.		Gallons.
Oklahoma.....	63	31,665,991	\$2,361,029	2.60
California.....	20	12,835,126	975,397	1.60
West Virginia.....	114	10,853,608	927,079	2.30
Pennsylvania.....	139	5,898,597	569,873	2.73
Ohio.....	50	2,198,715	167,138	2.80
Illinois.....	16	1,035,204	80,049	2.29
Texas.....	1			
New York.....	4			
Louisiana.....	2			
Kansas.....	2	877,424	70,258	1.32
Colorado.....	2			
Kentucky.....	1			
	414	65,364,665	5,150,823	2.57

^a Northrop, J. D., *Mineral Resources U. S. for 1915*, U. S. Geol. Survey, 1916, p. 997.

^b Includes gasoline resulting from natural condensation in gas mains.

In January, 1917, the number of plants in California had increased to 30, with an estimated daily production of more than 60,000 gallons, and the number of plants in Oklahoma to 95, with an estimated daily production of 200,000 gallons.

^a Allen, I. C., and Burrell, G. A., *Liquefied products from natural gas, their properties and uses*: Tech. Paper 10, 1912, pp. 4-7; Burrell, G. A., *The suitability of natural gas for making gasoline*: Tech. Paper 57, 1913, p. 17; Burrell, G. A., Seibert, F. M., and Oberfell, G. G., *The condensation of gasoline from natural gas*: Bull. 88, 1915, pp. 9, 10; Burrell, G. A., Biddison, P. M., and Oberfell, G. G., *Extraction of gasoline from natural gas by absorption methods*: Bull. 120, 1917, pp. 11-14.

FACTORS TO BE CONSIDERED IN EXAMINING FIELD FROM WHICH GAS IS TO BE TAKEN.

Before a compression plant can be properly designed to treat natural gas from any given area, a thorough study of the history of the field in general and especially of the sand from which the gas is to be taken should be made, also complete testing to determine the volume and gasoline content of the gas from the area under consideration should be made. This precaution is particularly necessary for a field in which there are no plants in operation that can be studied and used as a precedent.

A knowledge of the history of the field is important in determining the probable life of the wells and the decline in volume of gas produced from year to year. A plant built in California to treat 2,000,000 cubic feet per day has been able to get only half that amount because of the decline in gas production from the wells after the initial rock pressure was relieved, and new wells drilled for oil on the same lease have not thus far brought the quantity of gas up to the plant capacity. Gas from adjoining leases could not be obtained for treatment, and the plant at the time of the writer's visit was running at half capacity, as stated.

In all gas and oil fields in the United States it is found that as the pressure in the wells decreases the gas becomes richer in gasoline content. It is doubtful, however, if the actual total quantity of gasoline vapor from a given well increases, but it seems to be a fact that the amount of gasoline vapors produced declines much less rapidly than either the oil or gas production from a given well or area. This has been found to be practically true of West Virginia and California wells as long as the wells produce oil either under rock pressure or vacuum. In Pennsylvania a small compression plant is treating gas from wells that have long ceased to produce oil and are pumping salt water under vacuums of 26 inches of mercury.

New oil wells producing many million feet of gas under high rock pressure, such as are often brought in, in the Mid-Continent and California fields, are not considered, because gas produced under these conditions of pressure and volume practically never finds its way to compression plants. The gas produced under rock pressures of 400 to 1,500 pounds per square inch contains only comparatively small proportions of the heavier gasoline fractions and comparatively large quantities of the lighter or "wild" fractions, as would be expected from the condition under which the gas is held while in contact with the oil from which it must receive its charge of condensable vapors.

CHARACTER OF THE SAND.

A knowledge of the sand from which the gas is to be produced is a valuable factor in designing a plant; the thickness, texture, or degree of cementation bear directly on the future of the field as a

gas and gasoline producer. Thick sand of close texture indicates long life as an oil producer, and consequently a long life for gasoline production. Loose, uncemented sands, such as are found in California, will not withstand the suction of vacuum pumps, which causes the sand to come in and stop or injure the pumps. This inflow of sand reduces the production of oil and increases the expense of cleaning the wells, so that companies treating their own gas do not permit the vacuums held on walls to exceed 1 to 2 inches of mercury at the casing head. This limitation of vacuums may react in such a way as to make compression plants unprofitable when the oil production has become small and the rock pressure has been completely relieved.

CHARACTER OF THE OIL.

Casing-head gas produced with high-gravity oil is almost universally rich in gasoline vapors, except when the gas is produced under extremely high pressures. However, the fact that an oil is of low gravity can not always be depended on to indicate small gasoline content, as has been shown by compression practice in California. As a rule, in California, casing-head gas produced with oil having a gravity of less than 22° B. does not yield enough gasoline for profitable compression. However, in the Salt Lake field, the oil has a gravity of 15° to 17° B. and still the casing-head gas is commercially valuable for its gasoline content. Analyses by the Bureau of Mines^a of oil from this field shows that it carries exceptionally high proportions of asphaltum (55.3 per cent), but also carries lighter products, ranging up to fractions distilling over at 150° to 200° C., to which are due the gasoline vapors in the gas. The Kern River field, yielding oil with an average gravity of 14° B. has not, so far, produced any gas that is being treated for gasoline.

WATER SUPPLY.

Water being essential in all plants making gasoline by compression methods, the supply and the quality of water available should be carefully determined. The cooling coils and the compressor jackets of a plant treating 1,000,000 cubic feet of gas daily at a pressure of 250 pounds per square inch will use 100 to 300 barrels of water a day, depending on the design of the water-cooling system and the temperatures obtained. The loss is accounted for by the evaporation and, in plants where towers or sprays over ponds are used, by water being carried away by the wind. In the oil fields much of the water is so heavily charged with mineral salts as to be almost useless for boilers, gas-engine jackets, and compressor jackets. Such water to be made fit for boiler use must be treated with a so-called "boiler

^a Allen, I. C., Crossfield, A. S., Jacobs, W. A., and Matthews, R. R., *Physical and chemical properties of the petroleum of California*: Tech. Paper 74, Bureau of Mines, 1914, p. 13.

compound." For cooling jackets of machines the water must be condensed, otherwise it forms a scale, which interrupts the circulation of water and is dangerous both to machinery and to the operators, and also cuts down the efficiency of the engine and compressor by permitting overheating of the cylinders and of the gas being treated.

TRANSPORTATION FACILITIES.

The matter of transportation is of importance, as on it depends, in part, the questions of blending, size and weight of units, plant location, and length of pipe lines. Before a plant is designed, the most economical product should be determined, as it may be that producing the maximum quantity of condensate possible from a given gas will be as profitable as a smaller quantity of a less volatile product. Producing the maximum quantity of condensate from a gas requires high pressures and blending with naphtha as soon as possible after the condensate is precipitated. This requires machines to produce the high pressure, which adds to the cost of installation, and a continual supply of naphtha for blending. If the cost of freight on the naphtha coming to the plant and on the percentage of naphtha in the blended product going back to market, plus the cost of mixing and of losses in blending and handling, is greater than the value of the condensate produced in excess of the quantity that could be produced at a lower pressure without blending, it would be more profitable to produce less condensate of lower vapor tension capable of being shipped as made. For example, a plant in the Mid-Continent field, situated an excessive distance from the nearest refinery from which it could obtain naphtha for blending, finds that using a pressure of 80 pounds from single-stage compressors, and producing 1.8 gallons of condensate with a gravity of 75° to 80° B. and a vapor tension of 5 to 6 pounds, is more profitable than producing 3 gallons of condensate having a gravity of 94° to 98° B. and blending it at or near the plant.

The distance from a railroad will also have a bearing on the cost of erecting a plant. Pipe lines are usually built from the plants to loading racks or blending stations on the railroad. More recent practice seems to favor blending at the compression plant, which necessitates pumping the naphtha to the plant and pumping the blended product back to the loading station through pipe lines. The greatest expense from being at a distance from a railroad, however, is that of hauling equipment and repairs. Machines built in parts too large to handle on the wagons or trucks usually found in oil fields are much more expensive to place than machines shipped in smaller parts. Roads, distances, and the weights of large parts of machines should be considered when a plant is being designed or an estimate of cost figured.

Plate I, A (p. 24), shows two single castings weighing 31,000 pounds each, which were placed in a plant that could be reached only by narrow, steep roads. The trouble and expense of hauling such parts is a factor in plant construction.

The general topography at one compression plant is shown in Plate II, A (p. 24).

DISTRIBUTION OF WELLS.

If the wells from which gas is to be taken are distributed over a wide area, it is well to consider the construction of two or more smaller plants rather than one larger plant. One plant visited by the writer treats gas collected over an area of approximately 32 square miles. The extensive pipe-line system required to bring the gas to the plant and return it to the various leases, with the booster stations and equipment necessary to maintain them, makes this plant, in the opinion of the management, more expensive and less efficient than two or three smaller plants would have been.

CONDITION OF WELLS.

Before erecting a compression plant in an old field the condition of the casings in the wells from which gas is to be taken should be ascertained. In an old field in Pennsylvania it was found that the casings were badly rusted and allowed excessive quantities of air to enter the lines as soon as a vacuum of more than 1 or 2 inches was placed on them. The wells made an average production of only 1,000 cubic feet of gas a day, so that the expense of recasing would not seem to be warranted.

J. O. Lewis, petroleum technologist of the Bureau of Mines, states that air is often admitted to wells in which the casing has not been properly placed, the air entering through porous strata from other wells which are not being held under vacuums.

TESTING NATURAL GAS.

The testing, measuring, and sampling of natural gas for its gasoline content has been described in Bureau of Mines publications^a by G. A. Burrell and his associates, and will only be taken up briefly by the writer.

Many compression plants are successfully treating gas about which few facts were known before the plant was erected. Much time and expense could have been saved, however, if more had been learned of the physical and chemical characteristics of the gas before the plans

^a Burrell, G. A., and Jones, G. W., Methods of testing natural gas for gasoline content: Tech. Paper 87, 1916, 23 pp. Burrell, G. A., Selbert, F. M., and Robertson, I. W.: Analysis of natural gas and illuminating gas by fractional distillation at low temperatures and pressures: Tech. Paper 104, 1915, 41 pp. Burrell, G. A., Selbert, F. M., and Oberfell, G. G., The condensation of gasoline from natural gas: Bull. 88, 1915, 106 pp.

of the plant were made and the machinery installed. The investment in a compression plant is large enough to warrant the expense of having all necessary tests, analyses, and measurements of gas made and checked before the plans and details of construction are taken up.

SPECIFIC GRAVITY TEST.

Natural gas having a specific gravity of 0.78 (air = 1) and higher is being successfully treated in compression plants. The specific gravity test is useful as an indicator, but the possibility of misleading variations through the presence of other gases, such as air, carbon dioxide, nitrogen and sulphur compounds, in the sample makes this test unreliable if used alone. If an analysis is made of the gas and the specific gravity of the hydrocarbon contents computed, the results are more dependable, but even then are not reliable enough to be used as a basis for final decisions regarding plant construction.

SOLUBILITY TEST.

The solubility test described by Burrell and Jones^a is useful as an arbitrary test, because it is known that gases of a solubility of less than 30 per cent have not been successfully treated in compression plants.

In regard to the following table they state that "in all cases the yield represents the actual amount of gasoline sold after weathering."

Yield of gasoline from casing-head natural gas by compression method, corresponding to absorption and specific-gravity tests.^a

Absorption by oil.	Specific gravity (air=1).	Yield of gasoline, gallons per 1,000 cubic feet of gas.	Absorption by oil.	Specific gravity (air=1).	Yield of gasoline, gallons per 1,000 cubic feet of gas.
<i>Per cent.</i>			<i>Per cent.</i>		
16	0.64	None.	50	1.29	3.00
23	0.83	1.00	48	1.37	3.50
30	0.90	1.75	44	1.38	3.50
37	1.00	2.00	65	1.38	4.00
39	1.03	2.50	84	1.41	4.50
38	1.07	3.00	86	1.46	5.00
54	1.21	3.50			

^a Burrell, G. A., and Jones, G. W., work cited, p. 10.

It should be stated that both the specific-gravity test and the oil-absorption test fail when applied to residual gas from a gasoline plant because, although the results obtained will indicate high specific gravity and oil absorption, principally because of the presence of large percentages of the hydrocarbon gases, ethane and propane, yet the plant will have extracted the vapors of the liquid paraffins that constitute gasoline.

^a Burrell, G. A., and Jones, G. W., Methods of testing natural gas for gasoline content: Tech. Paper 87, Bureau of Mines, 1916, pp. 7-10.

FRACTIONAL DISTILLATION.

The Bureau of Mines ^a has developed a technical laboratory test based on a method of freezing out the propane and higher hydrocarbon fractions, which accurately determines the percentage of condensable hydrocarbons, including propane and all other higher members of the hydrocarbon series. This test can be made only in a well-equipped laboratory by experienced gas analysts.

Another method, based on the principle of low temperatures, that was originated by the Smith Emery Co., of Los Angeles, Cal., is essentially as follows: Gas from the casing-head of the well is led through a service meter (see fig. 1) under a pressure of 12 inches of water (devised so as to blow out if that pressure is exceeded) to a copper tube three-fourths of an inch in diameter and 15 feet long, coiled so as to fit into an asbestos insulated container 18 inches deep and 12 inches square. The container is filled with acetone (product of wood distillation) to within 2 or 3 inches of the top. Carbon dioxide snow from steel bottles of carbon dioxide in the liquid state is added to the acetone until a saturated solution is obtained. Complete saturation of the solution is shown when a portion of the snow remains, as snow, on the bottom of the container. The temperature of the acetone is held constant at 70° F. below zero by the carbon dioxide used in this way. Gas is passed through the copper coil, submerged in the acetone bath, until 500 or 1,000 cubic feet, as shown by the meter, has been treated; the coil is then drained into a flask, the quantity of condensate measured, and the gravity tested. If the condensate obtained in this manner is higher in gravity and vapor tension than would be desirable as a plant product, the condensate can be weathered down to the desired product, thus indicating the quantity of condensate of desired gravity which the gas contains. One series of tests made in this manner produced a condensate having a gravity of 90° B., and an absorption plant treating the gas reports a production approximately equal to the results obtained in the original tests of the gas. It requires 2 or 3 bottles of carbon dioxide to conduct this method of testing for one day, and the gas from 6 to 10 wells can be tested in that length of time.

PORTABLE COMPRESSOR TEST.

It has become the practice, in testing natural gas for its gasoline content to determine its suitability for use in a compression plant, to make actual physical tests with a small portable plant consisting of a compressor, meter, and cooling coils mounted on a wagon or

^a Burrell, G. A., Seibert, F. M., and Robertson, I. W., Analysis of natural gas and illuminating gas by fractional distillation in a vacuum at low temperatures and pressures: Tech. Paper 104, Bureau of Mines, 1915, 41 pp.

truck. Each well is tested by moving the compressor outfit to a point where gas can be taken from the casing head or from the gas line leading from the well.

The reason for testing each well separately is that even in the same field gas from different wells has widely varying contents of gasoline vapor, and if comparatively dry gas is mixed with gas of greater vapor content, the yield of condensate will be decreased or greater pressure and a lower temperature will be required to precipitate an equal quantity. This point was proved in practice by a plant in California, which, by turning out of its lines the gas from a well making about one-half million cubic feet per day, increased the plant production, no change being made in the pressure or the cooling system.

A portable testing outfit observed in operation by the writer consisted of a tank 12 by 36 inches used as a gas receiver, a 4-horsepower gas engine belted to a 3 by 3½ inch single-acting compressor with a capacity of 3 cubic feet per minute, a single coil of 1-inch pipe of the continuous, return-bend type cooled by submerging in a wooden trough of water and ice, and a double coil, 12 feet long, of 1-inch pipe inside a 2-inch pipe, cooled by expanding the compressed gas through a valve connection between the outside and inside pipes.

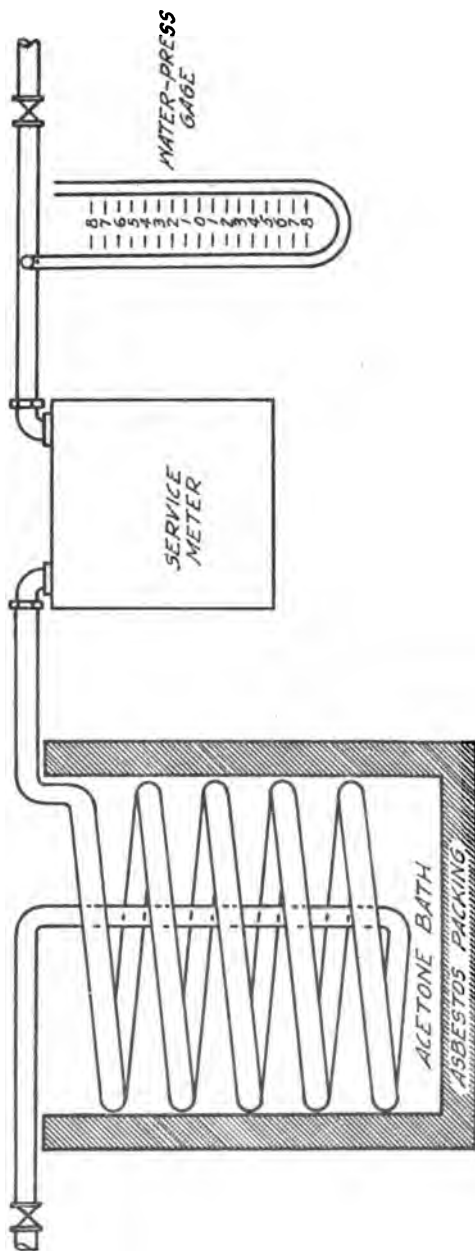


FIGURE 1.—Apparatus for testing natural gas by the acetone and carbon-dioxide method.

The gas was brought from the well line through a $\frac{1}{2}$ -inch pipe fitted with a water gage for regulating the pressure on the intake receiver; this receiver also served as a trap for heavy oil and dirt. From the receiver the gas was compressed and delivered to the water-cooled coil at a pressure of 250 pounds, the water being cooled with ice. Ice was used because it gave lower and easily regulated temperatures, was more convenient to obtain than a large or continuous supply of fresh cold water, and permitted tests to be run at nearly the same temperature and under more uniform conditions. The gas from the water-cooled coil discharged into the chamber between the outer and the inner pipe of the double coil. At the discharge end of the outer or 2-inch pipe was suspended a 1-inch drip pipe to collect the condensate. Gas from the 2-inch pipe was expanded through the valve into the inner pipe to refrigerate the high-pressure gas flowing through the outside pipe and discharged through a service meter to the atmosphere. Records were kept of temperatures, pressures, and amounts and gravity of condensate produced. The tests were made at night to aid cooling. From time to time specific-gravity tests of gas from individual wells were made and recorded. When the gas from any well dropped noticeably in gravity, a compression test was run on it, and, if found too low in gasoline content for profitable recovery, was turned into the fuel lines of the lease and was not treated.

SOURCES OF ERROR IN PORTABLE COMPRESSOR TESTS.

The greatest source of error in making tests with portable outfits is the meters. Service or domestic meters become inaccurate if operated at pressures above those for which they were made, and should be tested before use even at normal pressures, and during use should be protected from excessive pressures by a water or mercury pressure gage placed on the pipe ahead of the meter intake. Pressures of 8 to 12 inches of water are usually used with meters of this type. Some operators use two meters, one on the intake and one on the discharge of the portable tester, the indicated amounts of gas being averaged in calculating the production.

Results are apt to be misleading when gas being treated in the testing machine is not cooled to the same temperature as under plant conditions or compressed to the pressure used in the plant. Small portable testing compressors can be adjusted and operated under conditions so nearly simulating actual plant conditions as to give reliable data on which to base estimates of pressures, temperatures, and recovery.

MEASURING THE FLOW OF NATURAL GAS.

The following description of the orifice-meter method of gas measurement is from Technical Paper 87^a of the Bureau of Mines:

ORIFICE METER.

An instrument known as the orifice meter, for testing small flows of natural gas, is shown in figure 2. This instrument is simple in construction, consisting of a short 2-inch nipple, *b*, with pipe thread on one end and a thin plate disk on the other. The disk carried a 1-inch orifice, *a*, and a hose connection, *c*, for taking the pressure. The meter is especially intended for testing small gas wells and "casing-head" gas from oil wells. As a rule the flow of gas from an oil well is rather small, and it is not advisable to test the flow with a Pitot tube such as is used in testing large gas wells. In using the orifice tester it is necessary to know the specific gravity of the gas in order to obtain the flow.

Before the orifice well tester is attached to the casing head the well should be permitted to blow into the atmosphere until the head of the gas is reduced and the flow has become normal. Then the tester is attached by simply screwing it into the end of a 3-foot length of 2-inch pipe and the pressure is read in inches of water on the siphon gage, *d*. In the table^b the flow of the well, with values for gas of different gravities, is opposite the gage reading. The orifice in the instrument should be kept dry and uninjured; otherwise the gage reading will not be correct.

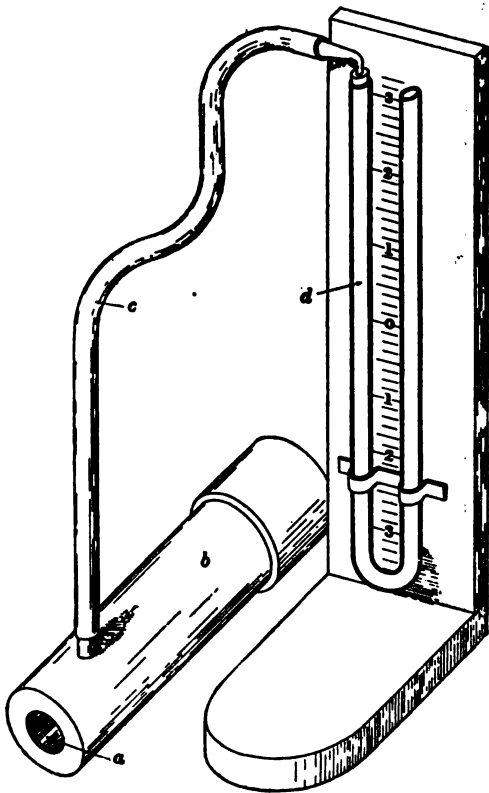


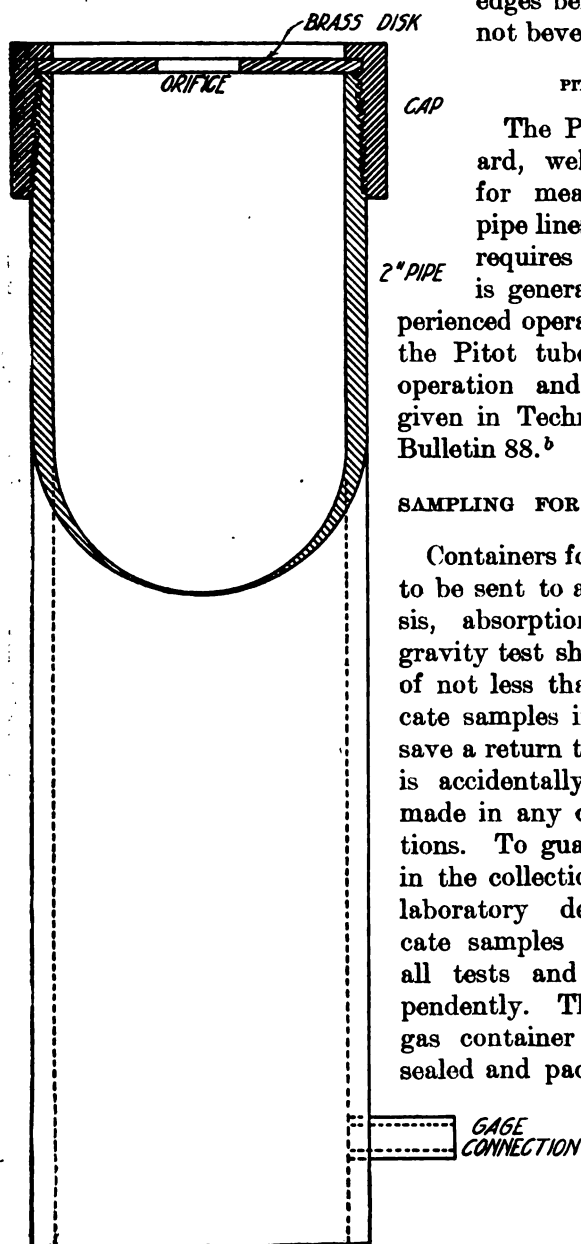
FIGURE 2.—Orifice meter for testing small flows of natural gas.

Beside the thin 1-inch orifice plate described above, orifice meters of this type are equipped with plates of the same thickness ($\frac{1}{8}$ inch) and with orifices of $\frac{3}{8}$, $\frac{1}{2}$, $\frac{3}{4}$, and $1\frac{1}{4}$ inch diameters for measuring flows of greater or less volume, and for checking, by two or more tests, the flow from the same well at different pressures. Figure 3 shows the design of meters in which are used a number of different sized orifice plates. The brass disks containing the orifices are carefully machined to a thickness of $\frac{1}{8}$ inch and are made to fit perfectly

^a Burrell, G. A., and Jones, G. W., Methods of testing natural gas for gasoline content: Bureau of Mines, 1916, pp. 18-20.

^b See Table 15, p. 115.

between the cap which holds the disk in place and the end of the 2-inch pipe. The orifice in the disk is accurately drilled to size, the edges being made square and not beveled.



PITOT-TUBE METHOD.

The Pitot tube is a standard, well-known instrument for measuring gas flows in pipe lines and at gas wells; it requires careful attention and is generally used only by experienced operators. Descriptions of the Pitot tube and its method of operation and tables of flow are given in Technical Paper 87^a and Bulletin 88.^b

SAMPLING FOR LABORATORY TESTS.

Containers for natural-gas samples to be sent to a laboratory for analysis, absorption test, and specific gravity test should have a capacity of not less than 1 pint, and duplicate samples in two containers may save a return to the field if a sample is accidentally lost or an error is made in any one of the determinations. To guard against errors both in the collection of samples and in laboratory determinations, duplicate samples are often taken and all tests and analyses run independently. The bottle or other gas container should be carefully sealed and packed to avoid leakage from poor stoppers and expansion and contraction of the gas from wide changes in temperature.

FIGURE 3.—Orifice meter in which different sized orifice plates may be used.

^a Burrell, G. A., and Jones, G. W., *Methods of testing natural gas for gasoline content*: Bureau of Mines, 1916, pp. 21-24.

^b Burrell, G. A., Selbert, F. M., and Oberfell, G. G., *The condensation of gasoline from natural gas*: Bureau of Mines, 1915, pp. 37-45.

COLLECTING A SAMPLE BY AIR DISPLACEMENT.

Filling a bottle or other container by air displacement is a rapid and convenient method, often used in the field. A small hose is placed over a pet cock in the gas line, the other end being inserted inside of the container. A gentle stream of gas is then allowed to flow into the container for four or five minutes, displacing the air. If the gas is known to be lighter than air it is best to invert the bottle, thus allowing the light gas to displace the heavier air; if the gas is heavier than air, the reverse method is preferable. The bottle is then quickly corked, and sealed by covering the stopper with a coating of warm paraffin. The difficulty with this method is the uncertainty whether all of the air has been displaced by the gas.

COLLECTING A SAMPLE BY WATER OR MERCURY DISPLACEMENT.

A more accurate method of obtaining a gas sample is by the displacement of water. In this method the bottle is filled with water and inverted beneath the surface of water in a bucket or other convenient receptacle, the hose from the gas line is allowed to discharge below the mouth of the inverted bottle until the water in it has been entirely displaced by the gas. The bottle is then closed or corked while still beneath the surface, and after drying and sealing with paraffin, can be transported without danger of contamination of the contents.

Mercury may be used in the same manner as water, but requires that considerable volumes of this liquid be kept with the sampling apparatus, which adds to its bulk and weight. Displacement of mercury is, however, the most accurate method of filling a container with the gas to be tested, and insures the least possible contamination.

SAMPLING AND TESTING IN GENERAL.

All tests, measurements, and determinations of natural gas to be used for gasoline manufacture should be checked and proved. Duplicate tests, analyses, and measurements should be made by different persons, if possible. If the duplicate results show variations large enough to be of importance in determining plant capacity, methods, or equipment, a third test should be carried out to determine which results can be trusted and can be used in plant design. Too much importance can not be placed on accurate testing and measuring of gas to be treated for gasoline content, for although during the treatment in a commercial plant many problems arise that can not be foretold, many characteristics of the gas can be determined which have a direct bearing on the pressures and temperatures necessary and the gravity and vapor tension of the condensates produced.

METHODS OF NATURAL-GAS GASOLINE MANUFACTURE.

Plants treating natural gas for its gasoline content fall under one of three mechanical and physical subdivisions—compression, refrigeration, and absorption, or a combination of these methods. Each division varies widely in mechanical details of both equipment and operation. Gasoline recovery by compression and refrigeration will be discussed in the following pages. Recovery by absorption methods has been described in Bulletin 120.^a

THEORY OF PRECIPITATION.

CONDENSATION BY COOLING.

The theory of the precipitation of vapors from natural gas is in a way comparable to that of the precipitation of water vapor from the atmosphere. Water vapor is known to exist in the air at all times in varying proportions, but is invisible unless condensed by cooling. Cooling to a temperature below that at which the air is saturated with the water vapor it contains causes precipitation in the form of snow, hail, frost, rain, fog, or dew. This fact is also illustrated by beads of water collecting on the outside of a pitcher of ice water, and by the formation of frost on the refrigeration pipes of expansion units, as shown in Plates V, C, VI, and VII (pp. 34 and 36). The air coming in contact with the cold surface of the pitcher or pipes is cooled below its dew point and the moisture which it can no longer hold as vapor condenses as water or frost on the surface. By further cooling of the air more moisture would be condensed, and if cooling were carried far enough practically all of the water vapor could be precipitated without the aid of pressures higher than atmospheric.

CONDENSATION BY COMPRESSION.

In plants compressing air it is found that air, after having been made more dense by increase of the pressure and decrease of the volume, deposits moisture at atmospheric temperature, and as the pressure is increased larger percentages of the contained water vapor are precipitated. Hence either high pressures or low temperatures increase the condensation of the water vapor.

In the exceedingly dry atmosphere of the Arizona and Nevada deserts, operating air compressors at a pressure of 100 pounds and cooling the compressed air only to atmospheric temperature always causes precipitation of water, and of lubricating oils from the cylinders, in the air receiver. That all of the moisture in the air is not deposited in the receiver is shown by the fact that in pumps driven by compressed air some moisture freezes in the cylinders and also forms frost on the exhaust outlet.

^a Burrell, G. A., Bliddison, P. M., and Oberfell, G. G., Extraction of gasoline from natural gas by sorption methods: Bull. 120, Bureau of Mines, 1917, 71 pp.

The condensable fractions in natural gas, like those in air, are not visible under ordinary conditions, but at times the sudden release into the atmosphere of gas from confinement under pressure will cause vapors of hydrocarbons to form a mist resembling fog or steam.

In the treatment of natural gas for gasoline recovery the result desired could be accomplished either by compression or refrigeration, but the complex mixture of gases and vapors complicates the problem. Without an exact knowledge of the various members and the proportion of each to the whole, an attempt to calculate the most suitable pressures and temperatures becomes little better than a guess, and the most practical solution is by tests and experiments. According to the law of partial pressures,^a if gas contains 10 per cent of condensable vapor and is under a pressure of 200 pounds, the condensable 10 per cent has acting upon it a partial pressure of 20 pounds, or 10 per cent of the total pressure. As the proportion of different condensable vapors in the gas becomes smaller through their partial condensation, the partial pressure acting on them also becomes less. The percentage of the gage pressure acting on any one of the gas or vapor constituents varies in proportion to the percentage of volume occupied by that constituent. If the constituent is condensable, condensation will lower its proportion to the volume of uncondensed gas to a point at which the partial pressure acting on it is too small to cause further condensation, leaving a portion of the vapor uncondensed throughout the entire treatment. As the acting pressure becomes lower, condensation tends to cease, but lowering the temperature will cause further condensation. Under constant gage pressures and decreasing temperatures, the largest percentage of the heavier hydrocarbons contained in the gas is recovered, and the losses are confined to the lighter members.

Although all of the condensable vapor and even the true gases can be liquefied by increasing the pressure or reducing the temperature sufficiently, the application of these processes in treating natural gas for gasoline is limited by the commercial considerations. Extremes of either pressure or temperature would yield condensates too volatile for commercial use, also the machinery and other equipment required would be expensive to install and difficult to operate and maintain.

To recover the valuable hydrocarbon fractions that are held as vapors in natural gas, only such pressures and temperatures are necessary as can be obtained by the use of machines and fittings of standard construction and capacities. As the power used to compress the gas heats it, developing power by expanding the compressed gas cools it. By using the cooled gas as a refrigerant, the

^a Lucke, C. E., *Engineering thermodynamics*, 1912, p. 481.

temperature necessary, in conjunction with the pressures obtained, to extract the maximum of commercial condensate can be developed.

The temperature and the pressure that will yield the most profitable results are those that together will recover the largest possible amount of condensates of low vapor tensions and as much of the lighter parts as can be so blended or handled as to conform with legal standards of safety and make a good motor fuel

ABSORPTION THEORY.

The absorption process for recovering condensate from natural gas is based on an entirely different physical property, that of the solubility of vapors in liquids. In this process the gas is brought into intimate contact with a liquid which dissolves or absorbs the vapors; these vapors are later distilled from the absorbing medium and condensed.

USE OF COMBINATION COMPRESSION AND REFRIGERATION PROCESS.

As shown above, the fundamental principles of the compression process are compression and cooling of the natural gas to pressures and temperatures at which certain hydrocarbons condense.

Plants of this character are erected to treat casing-head gas from oil sands or from sands closely associated with oil, the gas being brought to the surface either between the casing and tubing of an oil well or with the oil in the tubing. The quantity of gas from each well is usually comparatively small and in some installations as many as 500 or 600 wells are connected with one compression plant of not more than the average capacity.

The dry (treated) gas is, at most plants, used on the oil leases to drive the gas engines of the compression plant, and also for gas and steam engines in pumping and drilling wells. A few compression plants sell the treated gas for commercial use in cities or for manufacturing purposes. The cost of pipe lines and equipment necessary to deliver the small quantities of gas to market would, in general, be excessive. There is seldom much gas left after the quantity necessary for furnishing power has been used.

The value of the gas for heating, power, and lighting is not impaired appreciably by removing the gasoline content. If this gas were not treated, the gasoline would, at most leases, be burned with the gas used for power purposes and practically be wasted as far as serving any useful purpose is concerned.

GAS LEASES.

Until 1914 practically all the gas being treated for its gasoline content was sold or leased under varying conditions to gasoline producing and marketing companies independent of the companies pro-

ducing the oil. Since that time the oil producing companies, realizing the profits to be made, have constructed compression plants to treat the gas produced with the oil on their leases, and in many instances are now purchasers or lessors of gas from surrounding properties.

Before 1914 gas leases were made mostly on a flat rate, which varied from 2 to 5 cents per 1,000 cubic feet. Often the contract stipulated the vacuum to be held on the oil wells, and specified that any treated gas not used to run the compression plant was to be returned to the lease from which it was taken, the return gas lines to be paid for and laid by the purchasing party. Other leases required that a certain percentage of the gas delivered to the compression plant should be returned, this figure in some instances being as high as 80 per cent.

SLIDING-SCALE LEASE.

One lease in Pennsylvania required that 7 cents per 1,000 cubic feet of gas be paid the lessor when the price received by the lessee for gasoline in tank car lots during the preceding month averaged 10 cents per gallon or less, and an advance of 1 cent per 1,000 cubic feet for each advance of 2 cents in the monthly average price of gasoline. The gasoline company had made arrangements to sell the treated gas at 12 cents per 1,000 feet to a company which supplies gas to near-by towns. This was one of the few plants found by the writer that made such disposal of the dry gas.

Such a form of contract, known as the sliding-scale lease, is being used almost entirely at present in the Mid-Continent fields, except that usually the contract stipulates that gas after treatment shall be returned to the lease from which it was originally taken. It also provides that all gas necessary for power to operate gas and water pumps as well as the compressor plant, shall be taken from the treated-gas lines at no cost to the lessor.

At the present time (December, 1916) leases in Oklahoma are being made on what is known as the 4-10 or the 5-10 basis, meaning that the price paid for the privilege of removing and selling the gasoline from the gas is to be 4 cents or 5 cents per 1,000 cubic feet when the price received for the product is 10 cents per gallon, with an increase of 1 cent per 1,000 feet of gas for each additional 2 cents per gallon, as in the Pennsylvania lease previously mentioned. On the 4-10 scale, with gasoline selling at 18 cents per gallon f. o. b. the plant, the price paid for gas would be 8 cents per 1,000 feet.

WEAK POINTS OF LEASE.

There seems to be two very weak points in such a form of contract; one is that no account is taken of the present or future quan-

tity of condensate in the gas, and the other is that as the wells and field grow older the percentage of gas returned to the original owner will become progressively less and eventually will become nil. In the Glenn pool, Oklahoma, this point has been reached at some plants.

In one plant, to the knowledge of the writer, the volume of treated gas discharged is at times insufficient to furnish fuel for the engines running the pumps and compressors. This condition is quite usual in older districts such as Sistersville, W. Va., where dry gas is bought to operate the compression plants, or, as at one plant, electric power is purchased and is used to drive the compressors.

As the quantity of gas decreases, the owner will receive less for the gas and have less treated gas returned to him, being forced eventually to buy gas for lease power while the plant operator will, for a long time at least, make the same or a slightly decreased quantity of marketable condensate. It would seem that these conditions should be taken into account in the gas contract.

ROYALTY LEASES.

Royalty leases are made and held in some fields, particularly in California, but do not seem to have been generally used throughout the United States.

Before the compression process and its results became well known and understood, gas could commonly be obtained on a royalty of one-eighth of the value of the product marketed, but as the gas producers learned of the treatment and profits, royalties have increased. In California, as much as one-third of the value of the product for gas containing less than 2 gallons of gasoline per 1,000 cubic feet is being paid. The writer is reliably informed of a contract in Oklahoma under which a royalty of one-half is being paid, the gas producing between 4 and 5 gallons of gasoline per 1,000 cubic feet.

FACTORS CONTROLLING ROYALTIES AND LEASES.

The royalties and prices that can be paid for gas under lease for gasoline recovery depend on the following conditions:

Wells scattered over a wide area will necessitate an expensive gathering system, including pipe lines and pumps or booster stations, and the cost of operation and upkeep. The quantity of condensate in the gas is vital because the cost of a plant and of plant operation is practically the same for rich or lean gas. If the gas is to be returned to the original owner for use on the lease, the cost, upkeep, and operation of the return or "dry gas" line are to be considered. The distance from a railroad station and the length of pipe lines required to bring the blending naphtha to the plant and transport the product to the station, also the distance from a market, and the source of naphtha supply will have a bearing on production and marketing costs.

The time the lease or contract is to run is also a factor which directly affects the price that is to be paid for gas, as the total cost of installation must be paid out of net receipts by the time the contract expires.

In general, all the factors entering into any manufacturing enterprise must be taken into consideration when the price to be paid for gas leases or royalties is being set.

METHODS OF COLLECTING NATURAL GAS.

The term "casing-head gas," when strictly applied, means gas coming from an oil sand between the casing and the tubing through which the oil is pumped. This term, however, as used in connection with compression plants, has been broadened so as to apply to any gas rising with oil in the tubing, or from flow lines, and to vapors coming from oil in traps or flow tanks.

In eastern practice it is usual to collect only the gas coming up between the casing and tubing in wells which are usually held under high (20 to 26 inches of mercury) vacuums, no attempt being made to collect the gas coming up with the oil in the tubing or the light fractions given off in flow or storage tanks. Oklahoma operators collect gas at the casing head, and in some instances from flow lines and flow tanks. In California an entirely different practice has developed, because of the soft running oil sand in most California fields. The oil and gas from one or more pumping or flowing wells is led into a specially built tank, called a trap. Traps of different designs are so constructed and operated as to permit the separation of the oil and the gas at pressures either above or below atmospheric, as circumstances may require.

USE OF TRAPS.

Originally traps were invented and designed to work under pressure with the object in view of separating, collecting, and saving the gas and also the oil atomized and mechanically carried with the gas into pipe lines or into the atmosphere; also to hold in the oil the gasoline fractions that would otherwise be volatilized when the pressure on the oil was released; and, further, to allow the oil to absorb as much of the condensable fractions from the gas as possible, thus raising the gravity of the oil and in a measure saving the most desirable fractions of the crude product. As an instance of the use of a trap and its effect on the oil produced, F. B. Tough, of the Bureau of Mines, cites the use of one at a gusher in the Midway, California, field. This well when flowing through a trap produced oil having a gravity of 32.5° B., and when flowing uncontrolled under considerable rock pressure into a collecting sump produced oil, as collected in the sump, with a gravity of 26° B., a gain of over 6° B. resulting from the use of the trap.

Traps are of interest to the casing-head industry principally as separators of oil and gas, or, as developed and used by at least one company, for holding a vacuum on the oil to separate from it such fractions as will distill off at the normal temperature and under a vacuum of 5 to 15 inches of mercury, thus reversing the usual effect and method of trap operation.

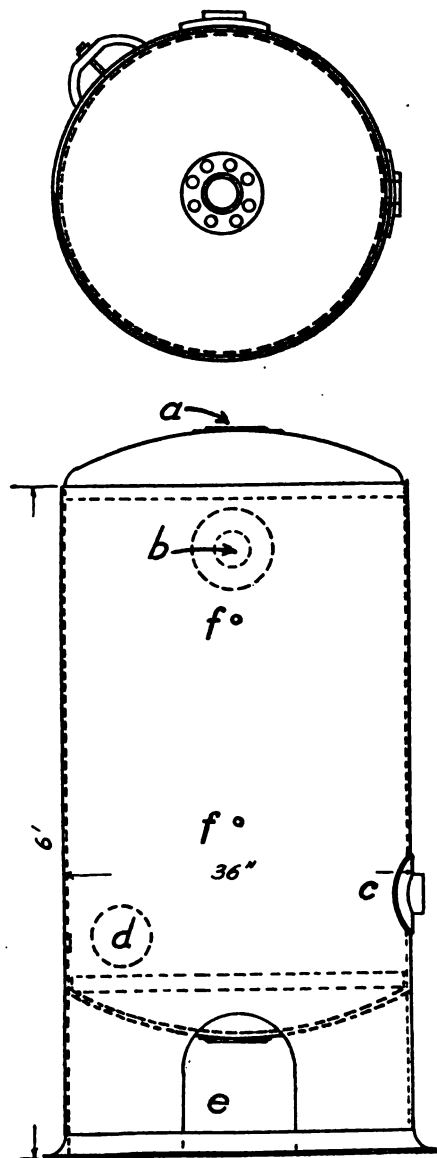


FIGURE 4.—Trap used with shallow pumping wells.
a, gas outlet; b, gas and oil inlet; c, oil outlet;
d, manhole; e, clean out; f, holes for gage glass.

TRAPS HELD UNDER VACUUMS.

This company had found that the crude oil during transportation and storage and in transfer to the stills of the refinery lost a part of the lighter fractions; also, the temperature used in cooling the still vapors permitted further losses of the lighter fractions, which could be collected as vapor and saved by treating in a compression plant with the gas and vapors produced at the wells.

The method adopted is to relieve the crude oil of its lighter gasoline fractions by holding a vacuum on the trap, as oil is sprayed or flows into it with the casing-head and tubing gases, and treating all the gas and vapors thus obtained in the compression plant. The condensate, which has a gravity of 86° B., is held under a pressure of 10 to 15 pounds and kept cool by shading or insulating the storage tanks until the product is blended with naphtha.

This company has three different production conditions to meet in the use of traps as follows: (1) Shallow pumping wells which have little or no gas pressure, (2) deep pumping wells with varying pressures of gas, and (3) deep flowing wells which have more or less pressure

on both gas and oil at all times and flow by head. Each condition is met by the use of traps of somewhat different design and operation.

Oil and gas from the shallow pumping wells is carried through flow lines, each controlled by a check valve, to a manifold, from which all the oil and gas goes through one line to a simple trap (fig. 4), the gas drawn out at the top at 5 to 15 inches vacuum to the scrubbers and vacuum pump, the oil being drawn off at a point near the trap bottom, to storage.

Production from deepwells flowing or pumping by "heads," which often builds up pressure in traps and lines by rushes of oil and gas too large for the normal capacity of simple traps and vacuum pumps, is handled by traps of special design, shown in figure 5. Two lines are laid from the well; one from the well tubing carries oil and gas pumped, or flowing together, the other line carries gas from between the casing and tubing. These lines are joined a few feet back of the trap intake, thus forcing all the gas and the oil to flow together into the trap at a point near the top; the gas separates from the oil and flows out at the top of the trap to the vacuum pump. The oil flows out near the trap bottom through a Crane balanced globe valve. The stem of the valve is rigidly connected to a counterbalanced float tank, which rises as the oil in the trap becomes low, closing the valve; fills and pulls the valve open when the flow increases and the oil rises in the trap. The float tank is connected both to the top and the bottom of the trap, as shown in figure 5, by swinging

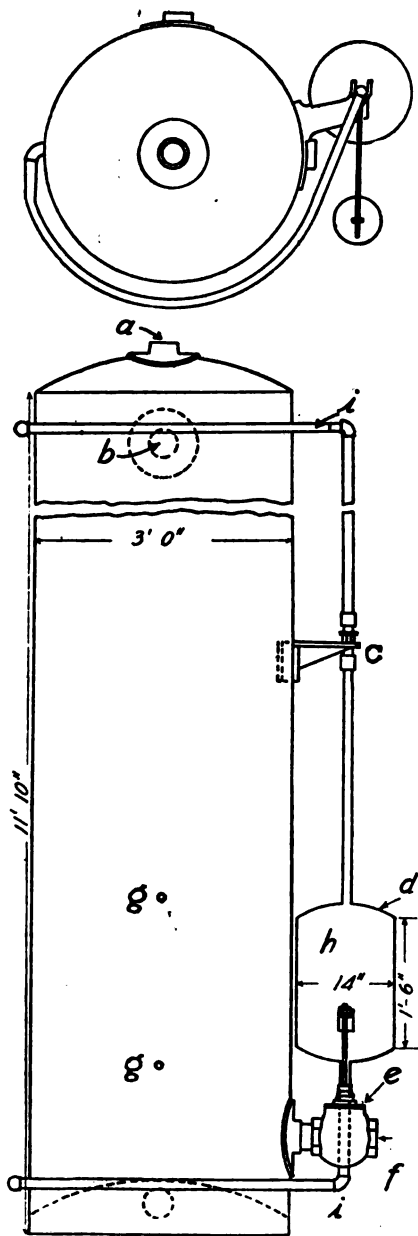


FIGURE 5.—Trap used on flow lines under pressure. *a*, gas outlet; *b*, gas and oil inlet; *c*, ball counter balance; *d*, float tank; *e*, 3-inch Crane balance globe valve; *f*, oil outlet; *g*, holes for gage glass; *h*, chamber; *i*, swinging pipe connections.

pipe connections. As the oil rises and falls in the trap oil flows in and out of the float tank through the bottom pipe connection. The top pipe connects the float tank and the top of the trap and acts only as a pressure equalizer. This trap is of standard design and is marketed by supply companies. The trap shown in figure 6 was

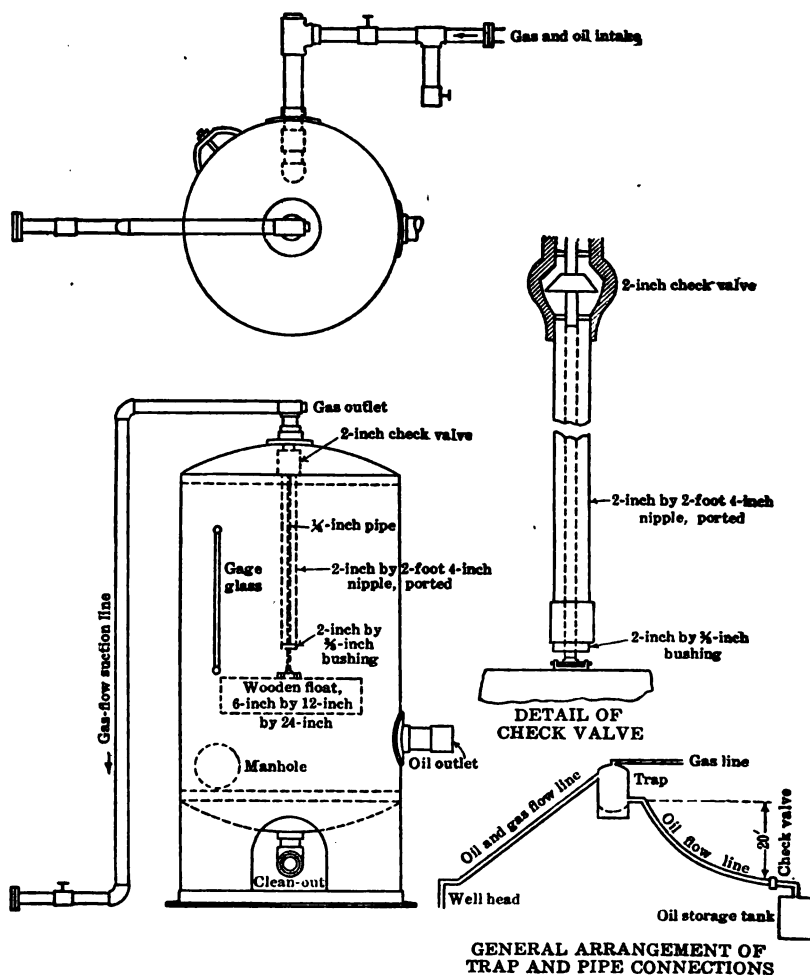


FIGURE 6.—Trap used with flowing wells.

designed by the company using this system of holding vacuums on traps. It is used, particularly with flowing wells, in much the same way as the trap shown in figure 5 and operates automatically.

When the oil level rises above a certain point the gas discharge shuts off entirely. This permits pressure to build up on both intake and discharge oil lines, causing a back pressure on the intake and a greater flow from the discharge; the trap thus clears itself and

returns to normal operation. It is set, as shown in figure 6, above both the well head and the storage tanks, so that when the oil and gas flow is small and a vacuum is built up in the trap the 20-foot drop and the horizontal check valve in the discharge line keep the oil from backing up into the trap, and permitting air to enter the trap and the gas lines.

As an example of loss of the light fractions of oil in storage, a 55,000-barrel storage tank filled with Cushing crude oil is reported by A. N. Kerr, of the Riverside Western Gasoline Co., to have lost by evaporation 9 inches, or 2.5 per cent of its total content, in one year. The loss, without doubt, consisted entirely of the light fractions that make up the gasoline content of the crude oil as it comes from the wells. Much of this loss might have been saved by using vacuum traps or by covering the tank and connecting it to the intake line of a compression plant.

FIELDS IN WHICH TRAPS ARE USED.

Traps are used more universally in the California fields than in other fields throughout the United States, because in California oil is sold on a gravity basis, making it desirable and profitable to retain as large a proportion of the light fractions as possible in the oil in order to keep the gravity at a maximum. The general practice, with the exception of the company using vacuum traps, previously mentioned, is to hold pressure on traps to save the light or gasoline fractions.

Plate I, *B*, shows a view of the Starke trap, designed and patented by Dr. Eric A. Starke, of the Standard Oil Co. of California, and used by that company.

Plate I, *C*, shows the McLaughlin compound trap, capacity 800 barrels of oil and 7,000,000 cubic feet of gas per day at 300 pounds pressure, patented by A. C. McLaughlin, of the Kern Trading & Oil Co., on the left, and the McLaughlin single-chamber trap, on the right. Plate III, *A* shows the cone chamber, McLaughlin trap.

Simple cylindrical traps used in the Fullerton field in conjunction with a casing-head gasoline plant are shown in Plate IV, *A*.

GATHERING LINES.

Gas from casing heads, tubing, traps, or flow tanks to be treated by compression is led through small (usually 2-inch) lines to a gas main that carries it directly to the plant or to a vacuum or pumping station.

At plants where the gas comes from near-by wells and the gathering lines are short, and it is not desirable to hold a high vacuum on the wells, the vacuum needed to carry the gas through the lines is

often developed in the low-pressure cylinder of the compression plant. By this method a vacuum pump is at many plants unnecessary, and the plant is simplified by requiring one less unit. From this condition the practice varies to plants at which gas is gathered from areas as large as 32 square miles, with 6 and 8 inch mains 7 to 10 miles long, and as many as 30 substations or gas pumps forcing gas through the pipe lines to the compression plant and holding the desired vacuum on the wells. In order to hold high vacuums on the wells from which gas is being drawn it is necessary to have the vacuum pump close to the wells, as it is impossible to maintain a minimum pressure through pipe lines of great length.

In designing a plant or plants to treat gas coming from a large area the number of plants, the number of vacuum and booster stations, the situation of the plant or plants, and the size and length of the pipe lines require careful mathematical calculations to determine the most economical installation. Many plants visited by the writer showed that little or no consideration had been given to these features. Such conditions may be due partly to the use of gas lines laid before the treatment of gas was considered and the reversal of the direction of flow in parts of such lines in order to bring the gas to the plant. The fall in pressure as the gas flows through the pipe lines and the increase in volume caused by the lowered pressure and the increased number of lead lines from wells as the gathering progresses toward the plant, make it essential to use pipes of progressively increasing diameter as the gas approaches the plant.

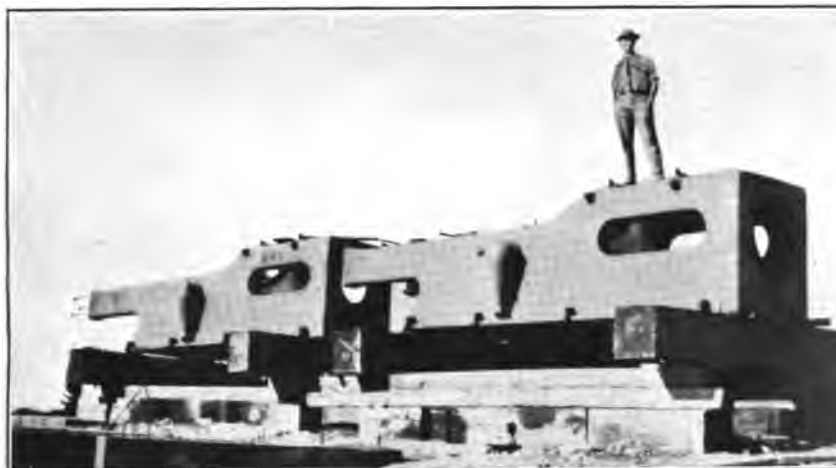
If vacuum pumps and booster stations are placed at points in the gathering lines to reduce the volume and increase the pressure of the gas, the lines leading from such plants may be smaller than those transmitting the gas under lower pressures.

In practice the sizes of gas mains have been determined usually by rule of thumb and bear little relation to the actual volumes, gravities, and pressures of the gas.

FLOW OF GAS IN PIPE LINES.

In designing gathering systems of compression plants to treat or pump gas, the determination of the proper size of pipe to use in lines for carrying a given quantity of gas at known pressures is so essential that the writer believes the formulas covering these points will be of value and interest to those engaged in compressing gas. Formulas and tables on the flow of gas in pipes have been developed by T. R. Weymouth, of Oil City, Pa., and discussed by him in a paper ^a written for and published by the American Society of Mechanical Engineers. These formulas, with that part of the paper that treats of the flow of gas in pipe lines, are given on pages 107 to 112.

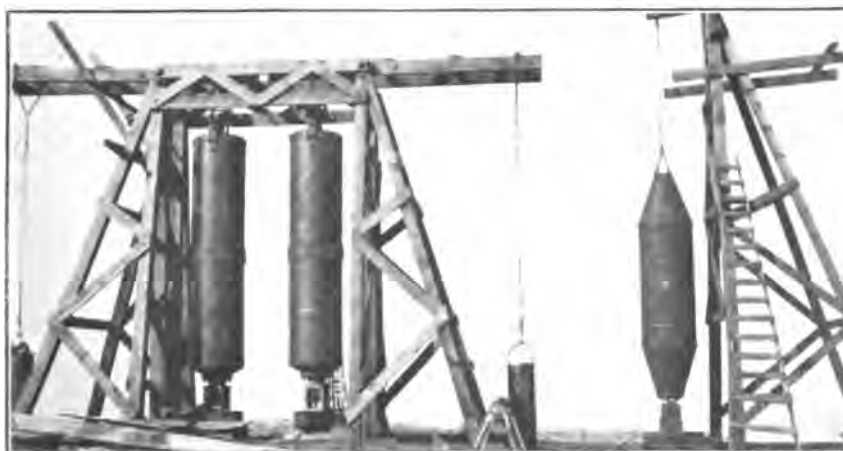
^a Weymouth, T. R., Problems in natural-gas engineering: Trans. Am. Soc. Mech. Eng., vol. 34, 1912, pp. 185-234.



A. TWO SINGLE ENGINE-BED CASTINGS, WEIGHT 31,000 POUNDS EACH.



B. STARKE TRAP AND CONNECTIONS, USED WITH GUSHERS MAKING LARGE QUANTITIES OF OIL AND GAS.



C. McLAUGHLIN COMPOUND TRAP (ON LEFT) AND McLAUGHLIN SINGLE-CHAMBER TRAP (ON RIGHT).



4. VIEW OF COMPRESSION PLANT.

Note tanks at left and cooling tower at right of compressor building.



7A. COMPRESSION PLANT; DAILY CAPACITY 7,500,000 FEET, BUILT ON SLOPING GROUND. HAS GRAVITY SYSTEM FOR HANDLING WATER AND CONDENSATE.

DRIPS AND SCRUBBERS.

Particles of crude oil are often carried into gas lines from flow lines, flow tanks, and traps; these, with fractions of heavy vapors condensed by changes in temperature and pressure of the gas in the transmission lines would, if not removed, cause trouble in the pipes, damage machines and meters, and discolor the condensate produced in the first-stage accumulators.

DRIPS.

Drips are placed at the low points in gas pipe lines to collect and remove condensed moisture and naphtha vapors and crude oil carried into the line, which if permitted to accumulate would restrict the passage and might do considerable damage by being forced through the line as a slug, forming a powerful hammer. The type of drip usually found is constructed of one or two lengths of 6 or 8 inch pipe capped at both ends and connected by a 1 or 2 inch pipe and valve, placed at the lowest point of a downward curve in the gas main. The liquids settling to this point drain into the drip and are either blown out and wasted, or, if the quantity and quality warrant saving, are collected in tanks and, after being distilled or filtered, are used for blending or are sold.

Officials of a plant visited by the writer gave the following data on "line distillates" collected by tank wagons from the gas-line drips:

Data on distillate collected from gas-line drips.

	Volume collected, gallons.
August, 1915.....	7,000
November, 1915.....	14,625
January, 1916.....	19,142
March, 1916.....	11,549

Average gravity for an entire year, 55° B.

The figures represent the total quantity of condensate collected during the month named and show the direct effect of atmospheric temperature on the quantity precipitated. The product as collected was discolored, but as all the condensate produced was shipped to the refinery with the crude oil in pipe lines, the color of the line distillate was of no importance.

SCRUBBERS.

The term "scrubber," as used in the casing-head gasoline industry, is restricted in its meaning to tanks for settling liquids out of the gas or to tanks fitted with baffles or some form of filter for removing liquids or dust from the gas, and is not used, as in the coke-oven or the artificial gas industries, to designate equipment in which certain constituents are removed by chemical action or absorption in liquids.

The usual form of scrubber is a vertical tank (see Plate IV, B) varying from 3 by 6 feet to 6 by 20 feet in size, with a gas inlet in

the side and near the bottom, the end of the inlet pipe being turned downward or fitted with a baffle, so that the gas discharges toward the bottom. The gas rises through the tank slowly, thus permitting particles of liquid or dust to settle.

Scrubbers of the filter type are of the same size and form as the settling tank, but have perforated horizontal partitions on which are various filtering mediums such as moss, hay, or sponge. When the filtering medium becomes saturated or dirty it is removed and burned, if moss or hay, or is cleaned and replaced, if sponge is used. Scrubbers are always put in pipe lines ahead of compression machines, meters, and the pump. They also serve as intake receivers for the gas pump or the compressor, one tank, 3 by 6 feet in size, being used on the intake of each machine, or a tank of corresponding larger capacity for the entire plant intake.

VACUUM STATIONS.

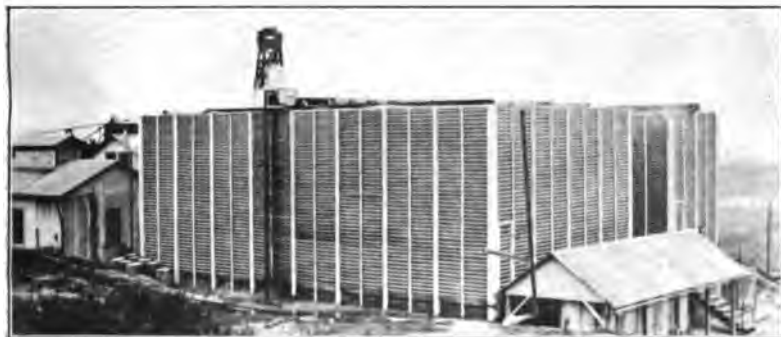
The number and the situation of vacuum pumps and booster stations on a gas-gathering system depend on the vacuum to be held on the wells, and the length and size of the pipe lines through which the gas is to be forced. When it is desired to hold the vacuum on the wells at the maximum, as is usual in the eastern fields, the vacuum pump must be placed near the wells, because friction, and often pipe-line leakage, reduces the suction on the well. The most common vacuum-pump installation consists of a gas engine of 35 to 70 horsepower belted to a duplex pump having cylinders varying between 10 by 17 inches and 20 by 20 inches. Intake pressures vary between 14 and 26 inch vacuums, and discharge pressures between a vacuum of 5 inches and a gage pressure of 5 pounds.

The "booster," if used, is to be placed in the same building as the vacuum pump. Power is developed by a 25 to 70 horsepower gas engine, either belted or direct connected to a compressor used to increase the pressure and force the gas through field lines either to another pump and booster or to the main compression plant. Compressors used in this way take gas directly from the discharge of the vacuum pump, usually holding a light (zero to 5-inch) vacuum at the intake, thus relieving the pump from working against high discharge pressures. Gas pumps are built too light to pump gas against pressures exceeding 10 pounds and usually discharge at nearly zero gage pressure. Compressors used as boosters deliver gas to the lines at pressures of 20 to 40 pounds and at any temperature incident to the compression.

Keeping gas under positive pressure through as much of the gathering system as possible tends to prevent air being drawn in and contaminating the gas, although any pressure high enough to keep air from leaking in also permits some gas, charged with condensable



A. McLAUGHLIN CONE CHAMBER TRAP.

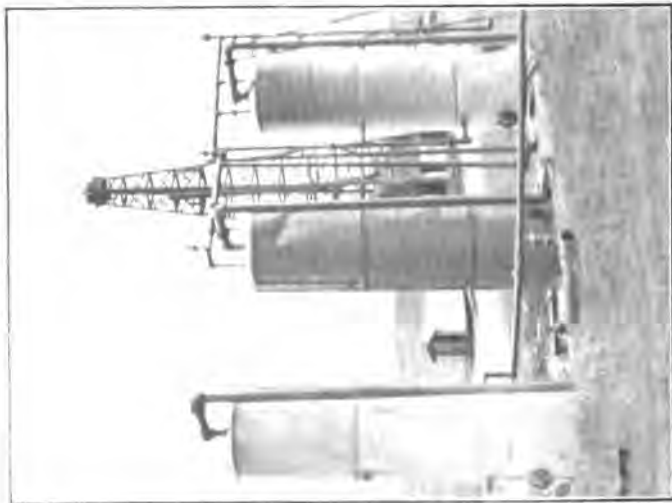


B. COOLING TANKS SET TO TAKE ADVANTAGE OF SLOPING GROUND AND OPEN-AIR CIRCULATION.

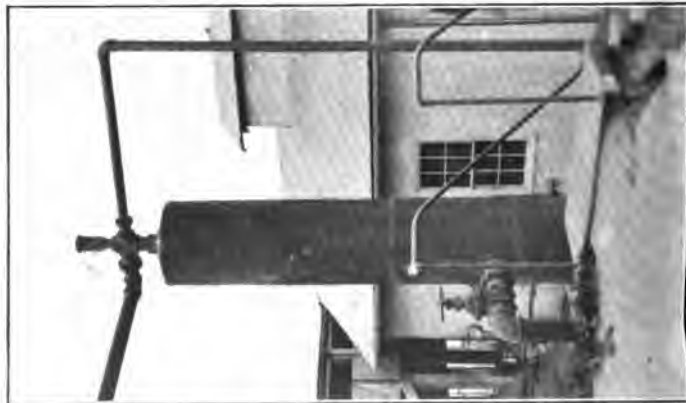


C. HIGH-PRESSURE AND LOW-PRESSURE ACCUMULATOR TANKS.

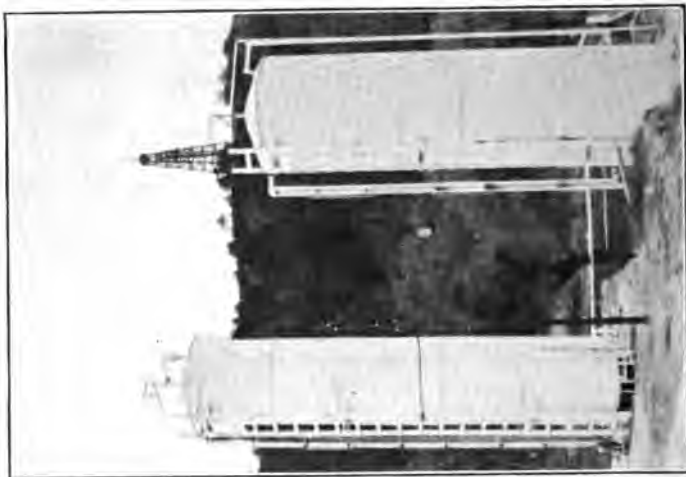
Note heavy double-riveted construction of high-pressure tanks.



A. SIMPLE CYLINDRICAL TRAPS.



B. INTAKE RECEIVER AT 1,000,000-FOOT PLANT.



C. "MAKE" AND STORAGE TANKS, SHOWING
PIPING AND PRESSURE VALVES.

vapors, to escape. Air in gas cuts down the volume of gas treated, necessitates the use of higher pressures to precipitate the condensate, and carries varying proportions of water vapor which condense with the gasoline. Another advantage of transmitting gas under pressure is that pipe-line capacities are increased, making possible the use of pipe of smaller diameter in the gathering system.

There is a decided tendency at the present time in favor of welded joints in pipe lines to carry gas either at vacuums or positive pressures. It is claimed that lines with such joints cost less in upkeep and repairs and can be maintained practically gas tight.

SITUATION OF PLANT.

Factors entering into the problem of the best situation for a compression plant to treat gas from a given area are so numerous and varied that no rules which would apply even in a general way to all conditions found in oil fields can be given.

The most important factors and those which will have the greatest weight in determining the most practicable situation for a plant are: Water supply, transportation facilities, and the length of gathering lines and return dry-gas lines necessary. In eastern fields an ample water supply can usually be easily obtained from a creek, river, or well, and causes little concern to plant operators, but in the Mid-Continent and the western gas-producing areas the question of water supply often becomes of major importance.

In the California fields some plants pay as high as 3½ cents per barrel for water, which has to be treated or condensed before it is fit for use in boilers or jackets. Other plants pump their water for distances of several miles, and at these the cost of installation, operation, and upkeep of the pumps and the pipe lines make the cost of water an important item. One California plant is using water separated from the oil in a dehydration plant on the cooling coils, and is distilling and condensing water for jacket use, all other sources of water having practically failed.

It is obvious that the nearer the plant is to the center of gas production the smaller will be the size of the pipe lines and the amount of power required to conduct the gas to the plant. However, other factors, such as water-supply and transportation facilities may affect the choice of a site. The plant should be so situated as to suit best all conditions, each being considered in regard to the others. Compression plants are often built on a hillside, advantage being taken of the natural slope to install a gravity system of handling the water and the condensate. The water, being drained from all points of use to one pond or basin, requires only one pumping unit to return it to the top of the towers or the storage tank above the plant, from which it is drawn for all purposes. Plates II, B, and III, B,

show plants using a gravity system for handling water and condensate. In this system the condensate can be run by gravity from accumulators and "make" tanks to storage and blending tanks. The accumulators do not have to be set in pits or cellars; this is a decided advantage, because gasoline vapor may collect in such pits unless they are thoroughly ventilated, in sufficient quantity to form an explosive or asphyxiating atmosphere and endanger the safety of the plant and the men. At plants visited by the writer three men have lost their lives by suffocation in pits filled with gasoline fumes. Some plants have a rule that a man before going into a cellar containing accumulator tanks shall notify another workman, or, if there is known danger from leaks, men shall work only in pairs or with a calling distance of each other. Plants are often built on a hill or rise because of the better ventilation and the cooling effect on water towers and coils.

DATA ON PLANT PRACTICE.

A number of tables compiled from data taken at each of the plants listed in Table 2 or given to the writer by owners or by officials of the various companies are presented herein.

In Table 2, column 1 shows the field in which each of the plants is situated. Each plant is given a number, shown in column 2, which it retains throughout all tables and discussions following. Capacity and production data of these plants are shown in columns 3 to 5. Column 3 shows the quantity of gas treated, in thousands of cubic feet, as estimated by plant operators, or computed from meter readings, or from the compressor displacement and the number of revolutions, or the pipe-line capacities at measured pressures. Column 4 represents the production, after weathering, of unblended gasoline and is approximately the quantity of condensate sent to market. Tank-car outage (or loss in transit) has not been deducted, as this factor varies widely with the distance traveled by the cars and the temperatures encountered during the shipment. Column 5 shows the number of gallons of condensate produced from each thousand cubic feet of gas treated, based on the plant capacity and the total product sold, as indicated in column 4. The gravity in degrees Baumé, as given in column 6, is determined from the plant product as a whole, before blending, or computed from the gravity of the blend, the quantity and the gravity of the blending stock used being known.

BLE 2.—Data showing situation, capacity, and output of the plants visited, and the gravity of the product.

Field where plant is situated.	Plant No.	Capacity (in 1,000 cubic feet).	Daily production, gallons.	Gallons produced per 1,000 cubic feet of gas.	Gravity, °B.
California fields:					
Fullerton.....	1	1,000	600	0.60	68
Do.....	2	350	1,200	3.40	76
Do.....	3	450	700	1.50	78-80
Do.....	4	1,250	1,600	1.30	72-74
Do.....	5	5,000	1,200	.24	
Santa Maria.....	6	2,500	5,500	2.20	81
Do.....	7	7,500	7,500	1.00	70
Do.....	8	500	500-600	1.00	70
Do.....	9	1,000	2,500	2.50	80
Do.....	10	750	1,200	1.60	74
Do.....	11	1,500	3,000	2.00	79
Do.....	12	700	1,500	2.10	81
Do.....	13	(a)			
Ventura.....	14	1,000	2,000	2.00	86
Do.....	15		800		
Salt Lake.....	16	250	325	1.30	65
Do.....	17	750	810	1.10	60-65
Do.....	18		1,500		68-70
Midway.....	b 19	1,800	1,400	.78	68
Do.....	20	1,500	1,400	.90	67
Do.....	b 21	1,000	700	.70	80
Western fields:					
Bradford, Pa.....	22	600	1,200	2.00	96
Sistersville, W. Va.....	23	200	800	4.00	88
Do.....	24	375	1,500	4.00	90
Do.....	c 25				
Do.....	26	500			88
Southern Illinois.....	27	750	500	.75	83
Do.....	28		200		83
Do.....	29				
1-Continent fields:					
Glenn pool.....	30	750	3,000	d 4.00	
Do.....	31	375	1,500	d 4.00	77
Do.....	32	3,000	22,500	7.40	84
Do.....	33	1,800	9,000	5.00	82
Do.....	34	750	5,250	7.00	82
Do.....	35	350	1,590	4.52	96
Do.....	36	2,000	2,310	1.10	78
Do.....	37	400	2,565	6.40	85
Do.....	38	750	5,055	6.70	
Do.....	39	200	510	2.50	
Do.....	40	250	600	2.40	
Do.....	41	350	550	1.60	
South Glenn pool.....	42	450	1,200	2.40	
Morris.....	43	300	300	1.00	
Do.....	44	500	1,850	3.60	
Beggs.....	45	350	710	2.10	
Muskogee.....	46	300	730	2.44	
Do.....	47	350	300	.85	
Glenn pool.....	48	1,200	2,380	2.00	
Cushing pool.....	49	2,000	2,810	1.40	
Cleveland.....	50	1,200	2,000	1.67	
Muskogee.....	51	250	925	3.70	
Do.....	52	250	500	e 2.00	
Cushing.....	53				
Nowata.....	54	f 2,250	10,000	4.00	
Do.....	55	1,250	1,600	1.30	
Do.....	56	380	600	1.60	
Do.....	57	830	1,500	1.60	
Morris.....	58	2,000	3,000	1.50	
Do.....	59	400	725	1.90	
Nowata.....	60	1,000	1,900	1.90	
Do.....	61	500	1,100	2.20	
Do.....	62	280	420	1.50	
Glenn pool.....	63	457	1,948	g 4.00	
Do.....	64	515	2,062	g 4.00	

a Plant not in commission.

b Plant capacities doubled and expansion sets installed or improved; product per 1,000 feet of gas increased.

c At this plant gas is compressed in one stage to a pressure of 150 pounds.

d Estimated.

e Eight per cent water with high and low pressure product.

f Thirty per cent air.

g Volume of gas estimated from product at 4 gallons per 1,000 cubic feet, a conservative estimate for steam wells in the Glenn pool.

TABLE 2.—*Data showing situation, capacity, and output of the plants visited, and the gravity of the product—Continued.*

Field where plant is situated.	Plant No.	Capacity (in 1,000 cubic feet).	Daily production, gallons.	Gallons produced per 1,000 cubic feet of gas.	Gravity, °B.
Mid-Continent fields—Continued.					
Glenn pool.....	65	90	350	4.00	.....
Do.....	66	90	351	4.00	.....
Do.....	67	98	384	4.00	.....
Do.....	68	136	545	4.00	.....
Do.....	69	125	500	4.00	.....
Do.....	70	141	566	4.00	.....
Do.....	71	712	2,864	4.00	.....
Do.....	72	375	1,500	4.00	.....
Do.....	73	466	1,864	4.00	.....
Do.....	74	124	496	4.00	.....
Do.....	75	173	690	4.00	.....
Caddo (Louisiana).....	76	2,000	3,600	1.80	.....
Do.....	77	400	640	1.60	.....
De Soto (Louisiana).....	78	45	350	7.00	.....
Caddo (Louisiana).....	79	250	1,050	4.20	.....
New Jersey: Refinery.....	80	1,750	5,400	3.00	76-8

^a Volume of gas estimated from product at 4 gallons per 1,000 cubic feet, a conservative estimate for gas from wells in the Glenn pool.

^b 50 per cent of this product was from low-pressure cylinder and 50 per cent from high-pressure cylinder and expansion coil.

In the following pages the writer has endeavored to describe as nearly as possible the treatment of natural gas in the recovery of gasoline by the compression process, and the mechanical units used.

The controlling functions of low and high pressure compression units of the plants studied by the writer are shown in Table 3.

Plant 2 is described in detail in pages 63 to 65. Plant 5 is a gas-pumping station, the condensate collected in cooling the gas before transmission is noted as production in Table 2 (p. 29). This gas after transmission through the pipe lines is treated in an absorption plant. Plant 10 uses three-stage compression. Plant 25 uses one-stage compression, compressing to a pressure of 150 pounds. Plant 80 is a refinery at which uncondensed still vapors are treated by compression; this plant is described in detail in later paragraphs.

PLANT INTAKE.

Table 3 shows that the temperature and the pressure at the plant intakes vary widely. The pressures tabulated as pressure at plant intake represent the pressure shown at the suction of the first-stage compression cylinder. Vacuum pumps, even if installed at the plant, are considered as part of the gathering system, and vacuum at plants where the compression cylinders are used to hold vacuum on the gathering system is taken as part of the compression operation and not as a part of the gathering system to which it rightly belongs. The intake pressures used vary from 18-inch vacuum to 5-pound pressure, and the temperatures from 60° to 125° F., the average

pressure being approximately that of the atmosphere, and the average temperature 80° F. The temperature of 60° F. noted above was recorded at plant 1, where the gas is cooled in coils placed in a water tower before it is compressed, and the temperature of 125° F. at a plant where a vacuum-pump discharge is used as the first-stage suction without cooling.

PRECOOLING.

Cooling the gas before it enters the first stage of compression, although not generally practiced, has distinct advantages. Reducing the temperature of the gas decreases the volume, the intake pressure remaining the same, so that more gas is taken into the compressor cylinder at each stroke, thus increasing the efficiency.

In warm climates plants having gathering lines, traps, and scrubbers exposed to the sun, which may heat the incoming gas to temperatures higher than 110° F., or having gas pumps and "booster" compressors in the gathering systems with no cooling coils after such units and before the plant intake, can by installing coils or other cooling apparatus increase both the plant efficiency and the carrying capacity of the pipe lines. Cooling the intake gas 30° or 60° F. will increase the quantity treated by a compression unit 5 to 10 per cent and lower proportionally the temperature of the gas discharged from the compressor. (See Table 11, p. 112.)

A plant in California lowered the temperature of the gas about 40° F. by passing it through a water-cooled coil ahead of the low-pressure intake. On the day of the writer's visit 1,250,000 cubic feet of gas was handled and the temperature lowered from 114° to 74° F. The coil used consisted of twelve 3-inch pipes 25 feet long, in 10-inch headers, placed horizontally in the cooling tower below the high and the low pressure gas coils.

A plant in Louisiana uses water cooling ahead of the vacuum pump and the first-stage compression intakes. In gas transmission gas piped to market is always cooled before being permitted to enter the mains, in order to increase the capacity of the line and to precipitate as much condensate and water vapor as possible.

TABLE 3.—Data on compression.

Plant No.	Low-stage compression.					High-stage compression.							
	Intake.		Discharge.		Cooling coils.			Compressor discharge.		Cooling coils.			
	Pressure, inches of vacuum.	Temperature, °F.	Pressure, pounds per square inch.	Temperature, °F.	Total surface area, square feet.	Square feet per horse-power.	Discharge temperature, °F.	Pressure, pounds per square inch.	Temperature, °F.	Rated horse-power.	Total surface area, square feet.	Square feet per horse-power.	Discharge temperature, °F.
1	10-15	60	40	(c)	500	0.500	60	220			500	0.500	60
2	11		37		220	4.00	68	250		55	220	4.00	68
3	2	(b)	55		150	3.91	70	240	240	150	150	3.91	70
4	3-10	72	50	240	1,225	4.70	81	250	190	900	1,225	4.70	78
5	0-1.4	78	54	200	3,600	4.00	76	260	245	160	3,600	4.00	78
6	6	80	35	245	475	2.97		200			475	2.97	
7	10	80	35		975	2.43		250			975	2.43	
8	7		40		585	2.80	65	190	235	240	585	2.80	72
9	2-5	65	36	240	450	3.05	70	225		165	450	3.05	70
10	5	65	43		504	3.05	70	250	200	155	504	3.05	70
11	(c)		50	200	167	3.35		240		150	167	3.35	
12	14	(b)	40		430	2.95		235		262	430	2.95	
13	9	(b)	35		660	2.87	78-80	275	250	247	660	2.87	70-80
14	13	(b)	35	250	528	3.50	68	260	250	150	528	3.50	68
15	20	68-80	50		146	1.63	130	300		90	292	3.26	60
16	6		40	190	100	5.90		90		17	150	8.80	
17	2-18		15		100			100		35			
18	12		10		(A)			300		100	350	3.50	70
19	30		25		(A)			300		100	350	3.50	70
20	6		50		(A)			300		100	350	3.50	70
21	6		50		(A)			300		100	350	3.50	70
22	6		50		(A)			300		100	350	3.50	70
23	6		50		(A)			300		100	350	3.50	70
24	6		50		(A)			300		100	350	3.50	70
25	6		50		(A)			300		100	350	3.50	70
26	6		50		(A)			300		100	350	3.50	70
27	6		50		(A)			300		100	350	3.50	70
28	6		50		(A)			300		100	350	3.50	70
29	6		50		(A)			300		100	350	3.50	70
30	6		50		(A)			300		100	350	3.50	70
31	6		50		(A)			300		100	350	3.50	70
32	6		50		(A)			300		100	350	3.50	70
33	6		50		(A)			300		100	350	3.50	70
34	6		50		(A)			300		100	350	3.50	70
35	6		50		(A)			300		100	350	3.50	70
36	6		50		(A)			300		100	350	3.50	70
37	6		50		(A)			300		100	350	3.50	70
38	6		50		(A)			300		100	350	3.50	70
39	6		50		(A)			300		100	350	3.50	70
40	6		50		(A)			300		100	350	3.50	70
41	6		50		(A)			300		100	350	3.50	70
42	6		50		(A)			300		100	350	3.50	70
43	6		50		(A)			300		100	350	3.50	70
44	6		50		(A)			300		100	350	3.50	70
45	6		50		(A)			300		100	350	3.50	70
46	6		50		(A)			300		100	350	3.50	70
47	6		50		(A)			300		100	350	3.50	70
48	6		50		(A)			300		100	350	3.50	70
49	6		50		(A)			300		100	350	3.50	70
50	6		50		(A)			300		100	350	3.50	70
51	6		50		(A)			300		100	350	3.50	70
52	6		50		(A)			300		100	350	3.50	70
53	6		50		(A)			300		100	350	3.50	70
54	6		50		(A)			300		100	350	3.50	70
55	6		50		(A)			300		100	350	3.50	70
56	6		50		(A)			300		100	350	3.50	70
57	6		50		(A)			300		100	350	3.50	70
58	6		50		(A)			300		100	350	3.50	70
59	6		50		(A)			300		100	350	3.50	70
60	6		50		(A)			300		100	350	3.50	70
61	6		50		(A)			300		100	350	3.50	70
62	6		50		(A)			300		100	350	3.50	70
63	6		50		(A)			300		100	350	3.50	70
64	6		50		(A)			300		100	350	3.50	70
65	6		50		(A)			300		100	350	3.50	70
66	6		50		(A)			300		100	350	3.50	70
67	6		50		(A)			300		100	350	3.50	70
68	6		50		(A)			300		100	350	3.50	70
69	6		50		(A)			300		100	350	3.50	70
70	6		50		(A)			300		100	350	3.50	70
71	6		50		(A)			300		100	350	3.50	70
72	6		50		(A)			300		100	350	3.50	70
73	6		50		(A)			300		100	350	3.50	70
74	6		50		(A)			300		100	350	3.50	70
75	6		50		(A)			300		100	350	3.50	70
76	6		50		(A)			300		100	350	3.50	70
77	6		50		(A)			300		100	350	3.50	70
78	6		50		(A)			300		100	350	3.50	70
79	6		50		(A)			300		100	350	3.50	70
80	6		50		(A)			300		100	350	3.50	70
81	6		50		(A)			300		100	350	3.50	70
82	6		50		(A)			300		100	350	3.50	70
83	6		50		(A)			300		100	350	3.50	70
84	6		50		(A)			300		100	350	3.50	70
85	6		50		(A)			300		100	350	3.50	70
86	6		50		(A)			300		100	350	3.50	70
87	6		50		(A)			300		100	350	3.50	70
88	6		50		(A)			300		100	350	3.50	70
89	6		50		(A)			300		100	350	3.50	70
90	6		50		(A)			300		100	350	3.50	70
91	6		50		(A)			300		100	350	3.50	70
92	6		50		(A)			300		100	350	3.50	70
93	6		50		(A)			300		100	350	3.50	70
94	6		50		(A)			300		100	350	3.50	70
95	6		50		(A)			300		100	350	3.50	70
96	6		50		(A)			300		100	350	3.50	70
97	6		50		(A)			300		100	350	3.50	70
98	6		50		(A)			300		100	350	3.50	70
99	6		50		(A)			300		100	350	3.50	70
100	6		50		(A)			300		100	350	3.50	70

38.	150	5	45	315	2.10	.420	250	150	330	2.56	.50	.....
39.	160	0	45	780	4.85	.650	250	160	1,470	9.20	1.23	.....
40.	55	6	45	147	2.70	.590	250	55	286	5.20	1.14	.....
41.	50	9	25	210	4.20	.840	250	50	610	12.4	2.44	.....
42.	.....	5	45	.....	.....	.....	250	.....	.....	.....	.....	.....
43.	.....	8	40	610	1.35	.270	250	450	975	3.16	.43	.....
44.	450	.....	40	.....	3.36	.404	250	150	505	3.36	.404	.....
45.	150	0	48	505	4.80	1.36	300	105	505	4.80	1.36	.....
46.	105	4-8	40	505	4.80	1.01	250	175	840	4.80	1.01	.....
47.	175	4-8	40	840	5.9	.88	.....	.....	.....	.....	.....	.....
48.	300	4-8	80	1,750	.....	.....	.....	.....	.....	.....	.....	.....
49.	50	0-3	90	580	11.80	1.47	.....	.....	.....	.....	.....	.....
50.	50	0-2	75	580	11.80	13.00	.....	.....	.....	.....	.....	.....
51.	52	0	50	126	2.42	.50	250	52	252	4.84	1.10	.....
52.	52	0	125	126	.....	.189	160	.....	.....	.....	.378	.....
53.	.....	0	43	253	.....	.....	.....	.....	.....	.....	.....	.....
54.	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
55.	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
56.	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
57.	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
58.	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
59.	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
60.	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

^a Ammonia process used from this point on.

^b Atmospheric.

^c Low-pressure cylinder; three stages used.

^d Intermediate cylinder.

^e 0.920, low compression; 0.680, intermediate compression.

^f Varied from positive pressure of 5 pounds to vacuum of 5 inches.

^g Pounds, positive pressure.

^h No coils used between low-stage and high-stage compression.

ⁱ At coil intake.

^j Single-stage plant, no blend ng.

FIRST-STAGE PRESSURES AND TEMPERATURES USED.

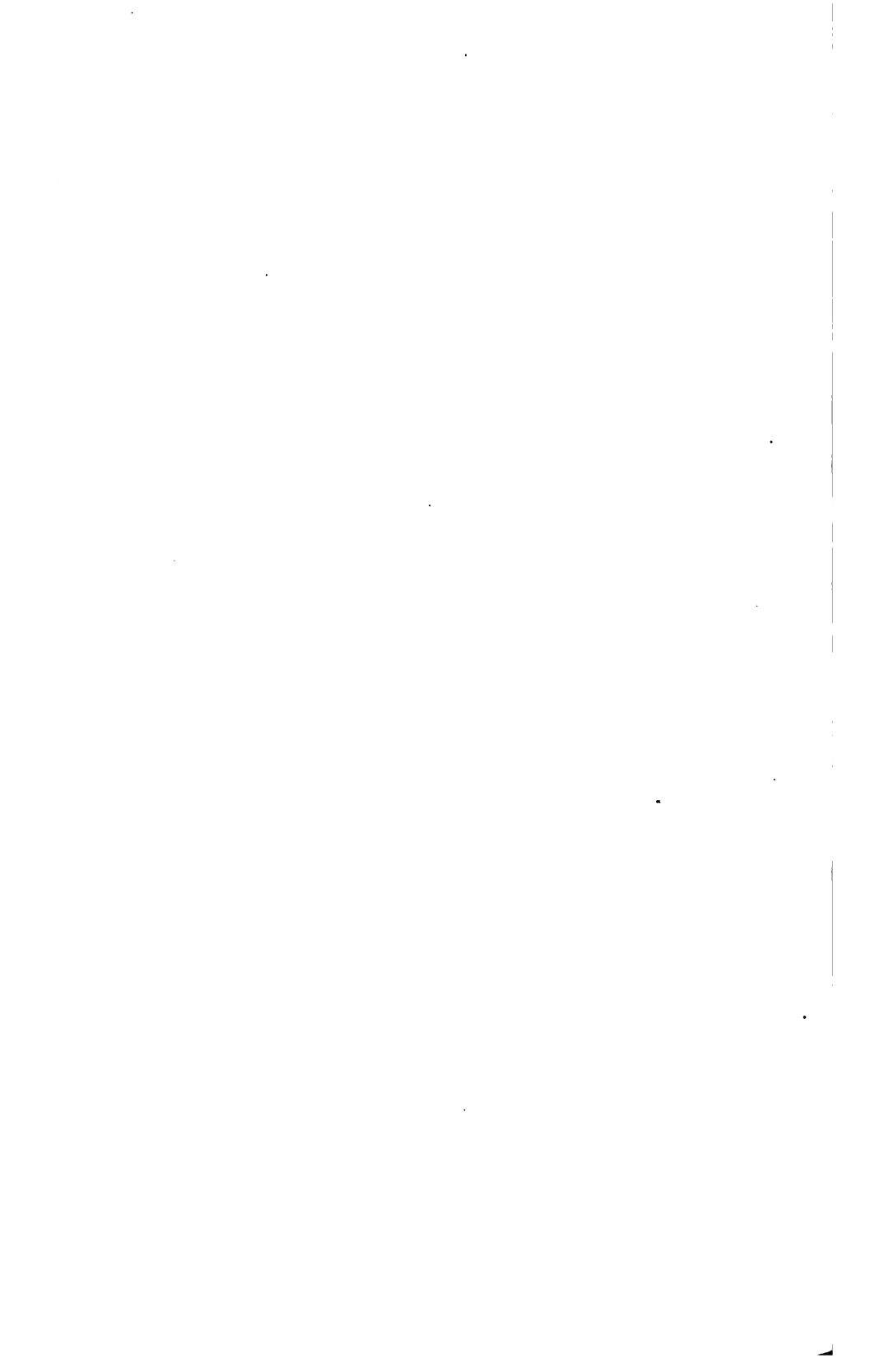
In plants using two-stage compression, the average pressure developed by the first stage is between 40 and 50 pounds per square inch; the temperature rises to between 200° and 250° F., depending on the temperature of the gas at the compressor intake and the number of compressions developed.

The increase in temperature of the gas from compression is a function of the power used to raise the pressure to the desired point. The power used depends on the number of compressions through which the gas is forced between its initial and final volume. As the amount of power actually expended, and not the initial and the final pressure, determines the rise in temperature the temperature increase due to a given number of compressions should be the same. If the intake temperatures of the high and the low stage compressor cylinder are equal, the final, or discharge, temperature of both cylinders of a two-stage compressor or of two single-stage machines acting as a high and a low stage unit should be the same, provided they are of equal horsepower and working properly and under uniform conditions. This is found to be approximately true in plant practice, as is shown by the temperatures of the compressor discharges given in Table 3.

The line carrying the compressed gas from either the high or the low stage cylinder is usually fitted with safety valves set to pop at pressures of 5 to 20 pounds above the desired pressure in order to protect the machine in case a valve farther along in the system may have been left closed or a pipe in the coils or other units in the gas circuit should become stopped or clogged, thus causing pressure to build up throughout the system. In plants using expansion engines this condition may occur at any time through the engine valves freezing, thus stopping the usual discharge.

ATMOSPHERIC COOLING.

The compressed gas discharged from the compressor is carried through an oil separator, placed just ahead of the cooling coils, which traps any lubricating oil vaporized in the cylinders or carried mechanically with the gas, the oil being condensed by the time the gas reaches the trap. Cooling to this point is effected by radiation to the atmosphere surrounding the gas discharge pipe and to the jacket water around the compressor cylinder. Some operators are employing air cooling extensively in order to save water, the practice being to use a much larger pipe, exposed as far as possible to the atmosphere, for conveying the hot gas from the compressor discharge to the water coils, thereby reducing the speed of flow and so increasing the time of transmission that the temperature of the gas is materially lowered. One plant with a daily capacity of 1,250,000 feet and using 6-inch pipe to carry both high and low



pressure gas to the coils, reduces the temperature between the compressor discharge and the coil intake 80° (240° to 160° F.) even in warm weather. In cold weather the reduction is greater.

Methods of air cooling are being rapidly developed and installed in districts where water is scarce and expensive, or the supply uncertain.

COOLING COILS.

In the eastern fields the cooling coils are generally of the continuous, submerged type, consisting of a 2-inch pipe 20 feet long, submerged in a tank of water. The total length of the coil varies between 300 and 500 feet, and the radiating area is 0.6 to 0.7 square feet per 1,000 cubic feet of plant capacity, and 2 to 5 square feet per horsepower used in compression. A continuous flow of water through the tank cools the gas to approximately the same temperature as the water.

In western and Mid-Continent practice a different method has been developed. Because of the difficulty of obtaining a continuous supply of cool water, it is necessary to use the same water over and over again in a closed circuit, the water being cooled in towers or in sprays over the principal storage pond or basin.

COOLING WATER BY EVAPORATION AND RADIATION.

Water exposed to air cools in two ways—by radiation, as long as the water is warmer than the air, and by evaporation.^a To obtain the greatest cooling effect the water must be so exposed to the air as to present the greatest possible surface. At some plants the water is cooled in towers (Pl. V, A) by means of sprays, or by permitting the water to fall in small streams on wire netting or screens, usually placed above the coils, thus atomizing the water and presenting a large surface to the air. The falling spray is often collected by V-shaped troughs that are placed a few inches above the top pipe of the coil and direct the flow of cooled water over the entire series of pipes. The water, dripping from the lowest pipe of the coil, is collected in a shallow basin beneath the coil and the tower, pumped to the top of the tower, and used again.

Plates VI and VII show views of a compression plant and the general arrangement of towers, compressor building, and storage tanks.

Some plants use a spray over a pond. The water is collected beneath the coils and conducted to a cistern from which it is pumped through upward sprayers placed over the storage pond, thence it is again pumped over the coils. The finely divided particles of water in the spray are cooled by radiation and evaporation while falling into the main body of water below. This system, although producing

^a Hausbrand, E., *Evaporating, condensing, and cooling apparatus*, 1903, 400 pp.

satisfactory temperatures, wastes more water than the tower installations, more being carried away mechanically by the wind; there is also a waste due to seepage, if the pond is of earth. The surface of the water in the pond is often exposed to the heat of the sun, which warms the body of water after cooling and before use over the coils. The sun has a decided effect in raising the temperature of the water in regions where the weather is warm during a large part of the year, as in Oklahoma and southern California.

WATER COOLING IN TOWERS.

In towers, during hot dry weather, temperatures 10° to 40° F. below that of the atmosphere are at times obtained with minimum losses of water. Many plant operators who have not experimented to find the amount of water that gives the lowest temperature to the gas being treated, use far more than is needed or gives the best results. Water falling in excessive quantities in a tower does not acquire the lowest possible temperature from radiation or evaporation, and the large bulk of water flowing over the coils can not cool the gas as efficiently as a smaller amount does, for the same reason. The best results are obtained when minimum quantities of water are circulated and finely divided while passing downward through the tower. Only enough of the cooled water should be directed onto the pipe coils to keep all parts thoroughly wet, thus giving the water the greatest possible opportunity to evaporate.

The use of auxiliary cooling agents such as ammonia or ammonia and brine is discussed later in connection with the descriptions of plants using such methods.

It may be of interest and use to operators to note here the latent heats of vapors being treated in the cooling coils. Burrell^a gives the following values for the latent heats of some petroleum distillates:

Specific gravities and latent heats of four distillates.

	Specific gravity, °B.	Latent heat, B. t. u. per pound.
Kerosene.....	43	105
Naphtha.....	56	103.5
Gasoline.....	65	100.6
Gasoline.....	89	100.2

In gasoline computations it is customary to use as the latent heat 100 B. t. u. per pound. Kent gives the specific heat of liquid gasoline of specific gravity 0.68 to 0.70 as 0.53 to 0.55, and Lucke^b quotes Regnault as stating that methane gas has a specific heat of 0.5929 at constant pressure and 0.4505 at constant volume.

^a Burrell, G. A., Personal communication.

^b Lucke, C. E., *Engineering thermodynamics*, 1912, p. 578.



VIEW OF 2,500,000-FOOT PLANT SHOWING ARRANGEMENT OF COMPRESSOR BUILDINGS, TOWERS, AND STORAGE TANKS.



ANOTHER VIEW OF PLANT SHOWN IN PLATE VI.

TYPES OF COILS AND CONNECTIONS USED.

Two systems of pipe connections are used between compressor discharges and cooling coils. In one system all low-stage compressors, and likewise all high-stage compressors, discharge the compressed gas into a common pipe or manifold, from which it is distributed by a manifold to the different sets of coils being used to cool the hot gas. (See figure 9, page 50.) The other system is to lead the gas discharged from each cylinder through a separate coil which cools only the gas from that compressor, the gas treated by each unit being kept separate throughout its entire circuit. The first method has the advantage of permitting one coil to be shut down or cut out for repairs while the compressor is running, the discharge from that machine being cooled in the coils still in use, or conversely, the coil may remain in use while the compressor is idle, and treat gas from other units. In the second method of connection if any coil or machine is out of commission the entire unit of which it is a part must be stopped, causing more of the plant to be idle.

Throughout the districts making natural-gas gasoline the 2-inch pipe in cooling coils is standard, and only a few plants using other sizes were found by the writer.

Systems and methods of connection vary widely, ranging from continuous return-bend coils in which all of the gas passes through the entire coil, to coils which divide first into two or more headers, and then into numerous separate pipes. In the multiple-header system each portion of gas passes through short lengths (20 to 80 feet) of the coil, and is again collected by headers before going to the accumulator tank and to the next stage of treatment. In the continuous system the gas passes rapidly through the total length of pipe, its temperature being reduced during the whole time of travel from end to end of the coil. In the multiple method the rate of flow in each pipe is reduced in proportion to the number of pipes used, so that the gas is sufficiently cooled while traveling through such a short length of coil.

There is much difference of opinion among operators as to which method gives the more satisfactory results. Many of the newest plants combine the two methods, as follows: Each coil unit is divided at the intake by a header into 3 to 12 sets of 2-inch continuous return-bend coils, each being 4 to 16 pipes high, and generally 20 feet long, depending on the cooling area desired. The intake header is placed horizontally at the top of the coil so as to allow the gas to travel downward in the same direction as the condensate. At the lower end of each set of return-bend coils the gas and condensate are again collected in a header before passing to the accumulator tank. Coils of this type and of the single-pipe continuous type have

the great disadvantage of being "hard to get at" in case any length of pipe in the coil needs replacement, whereas in multiple-header coils in which the ends of each pipe are packed in a gland, any member can be removed or replaced without taking down any other part of the coil.

DIRECTION OF FLOW OF GAS AND CONDENSATE.

It is universally conceded that the direction of flow of gas and condensate should be parallel and not countercurrent. As the liquid will drain toward the lowest point in the coil, the gas must enter at the top in order to flow with the condensate. As an illustration of the effect of counter flow, a plant in the Caddo field using a countercurrent flow of gas and condensate in the water-cooled coils produces no condensate whatever in the accumulator tank at the end of these coils. The gas yields 11.8 gallons of condensate per 1,000 cubic feet treated, but this condensate is all precipitated in double-pipe condensers cooled by expanded gas to a temperature of 38° F., in which the flow of gas and liquid are parallel. Undoubtedly some condensate would be precipitated in the water-cooled coil if the direction of gas flow was reversed. Other plants have obtained similar results under like conditions; one example being a California plant, in which the coil discharge pipe sloped upward to the accumulator tank, permitting condensate to gather in the bottom coils and discharge pipe and be constantly in contact with flowing gas. The accumulator tank was lowered so as to allow a drop in grade from the coils, with the result that the yield of condensate at that point increased noticeably. It seems that the condensate on long and intimate contact with the gas as above described, is again taken up by the gas as a vapor, even at high pressures, and carried to some point more conducive to precipitation and separation.

That condensate vaporizes in accumulator tanks has also been proved and has given rise to the practice of trapping off the liquid as soon as collected. Because of the facts stated, it appears to be the best and most productive practice to separate the gas and condensate as soon as possible after all the condensable fractions have been precipitated and always to allow the gas and condensate to flow in the same direction. If the above arguments hold true under all conditions, it would seem to be advisable to divide the gas to be cooled into a number of coils or pipes that will retain it only long enough to obtain the maximum cooling effect from the water used, and to separate the gas and condensate as soon as possible.

In order to divide the gas from a header equally in each of the coils or pipes of a coil, an orifice disk is sometimes placed in the intake from the header; the constriction causes a slight back pressure, forcing the gas to enter each coil in approximately equal quantities. The

orifice is arbitrarily determined by making the sum of the orifice openings equal to the cross-sectional area of the pipe leading the gas to the header from the compressor discharge manifold, as the case may be.

RADIATING AREA OF LOW-PRESSURE COILS.

In Table 3 the total surface areas of coils used in cooling gas from cylinders of various plants visited by the writer are tabulated. It shows the area per 1,000 cubic feet of gas treated per day; also, per horsepower used in compression. The average area of coils is between 0.6 and 0.7 square feet per 1,000 cubic feet of gas daily and nearly 3.5 square feet per horsepower used in compression.

The latter factor is more useful for plant design, as the heat required in compressing gas is a function of the power used in compression and not of the volume of gas being treated. A cooling area of 3.5 square feet per horsepower is usually used at gas-pumping plants and has proved satisfactory in most fields.

In Table 3, gives the temperature of the gas leaving the water-cooled coils at plants where such data was recorded. Minimum temperature should be maintained to prevent the maximum percentage of condensate and benefit high-pressure compression, as explained in previous paragraphs.

After these coils the gas passes to the low-stage accumulator tanks. A separate tank may be provided with a separate tank or all the coils may be folded to one tank. Plate III, *C* (p. 26), shows the alternate arrangement of accumulator tanks of high and low pressure coils, each having a separate tank. The tanks are usually 3 to 4 feet in diameter by 6 to 10 feet high. The gas is led in at the side of the tank or at the top through a pipe turned or baffled downward inside the tank, discharging at a point about midway between the top and bottom. The condensate settles to the bottom; the gas discharges at the top to the intake line of the high-pressure cylinder if each unit is independent or to the high-pressure intake manifold if that system is used.

High and low pressure coils, with intakes alternating, used at one plant are shown in Plate V, *B* (p. 34).

PRODUCTION FROM LOW-PRESSURE TREATMENT.

The proportion of condensate collected in the low-stage accumulator tanks averages 15 to 30 per cent of the total yield and varies between nothing and 40 per cent, depending on the content of condensable hydrocarbons in the gas and on the temperature and the pressure used. Operators permit condensate to accumulate in the tanks until the incoming gas is forced to pass through it, or to accumulate for a given time and then run it into the storage tank through a hand valve.

The general practice, however, based on the theory that to separate gas and condensate as soon as possible produces the best results, is to remove the condensate from the accumulator tanks continuously with a small automatic trap that dumps often and with but little agitation keeps the tank practically empty at all times.

HIGH-PRESSURE TREATMENT.

From the low-pressure accumulator tanks the gas passes into the high-pressure cylinder of the compressor, and the cycle is repeated except that the higher pressure causes the lighter hydrocarbons to condense.

RADIATING AREA OF HIGH-PRESSURE COILS.

Table 3, which gives the average surface areas of both high and low pressure cooling coils at the plants visited, shows that a somewhat larger cooling area is used for the high-pressure gas. The area of high-pressure coils per 1,000 cubic feet of gas cooled daily was between 0.7 and 0.8 square feet and about 4.5 square feet per horsepower used in compression, whereas that of the low-pressure coils averaged between 0.6 and 0.7 square feet per 1,000 feet of gas and 3.5 square feet per horsepower. If the same amount of power is used by each cylinder of the compressor, there seems to be no reason why one cooling area should be larger than the other, unless the gas was not cooled in the low-stage coils to the temperature later obtained in the high-pressure coils.

The experience of A. W. Peake,^a engineer in charge of gasoline production of the Mid West Oil Co., causes him to "believe that the coil area of the intercooler should be larger than the area of the aftercooler coils, as it permits condensation of more gasoline in the intercooler and reduces the chance of carrying condensate over into the high pressure cylinders, causing trouble by cutting the lubricating oil and thus wearing out the cylinders in a short time. This trouble has been experienced in quite a few plants. Increasing the intercooler area has been known to help overcome this, as also has been the placing of a steam or oil trap or some similar arrangement in the gas line, between low-pressure accumulators and high-pressure cylinder intake."

PERFECT COOLING.

Perfect cooling between low and high stage compression implies cooling the gas before it enters the high-pressure cylinder to the same temperature that it had on entering the low-stage unit. Such cooling is necessary if the two stages are to use the same amount of power in compressing equal quantities of gas an equal number of compressions. As shown in Table 3, the temperature of the gas

^a Peake, A. W., Personal communication.

At the low-stage intake is usually higher than at the high-stage intake. Such a condition would, if the number of compressions were equal in each stage, cause an unbalancing of power in the high and the low pressure cylinders. In compression plants with imperfect cooling between stages the work in the cylinders is allowed to take care of itself in such a way that the number of compressions in the two stages is not exactly equal. As stated in previous paragraphs, it would be better practice to cool the gas at the plant intake to as low a temperature as practicable in water-cooled coils and to use the same temperature between compression stages and in the high-pressure coils. In general, to keep the gas at the lowest practicable temperature at all times during treatment is the best practice. From the high-pressure coils and accumulators the gas passes to the old fuel lines or, if expanded gas is used to reduce the temperature still lower, it is led to the high-pressure coils cooled by expanded gas.

USE OF EXPANDED GAS FOR COOLING.

TABLE 4.—Data on cooling of gas by expansion at various plants.

Plant No.	Discharge temperature of gas cooled in high-pressure coils.	Method of expansion.	Expansion unit discharge.			
			First stage.		Second stage.	
			Temperature.	Pressure.	Temperature.	Pressure.
	° F.		° F.	Pounds.	° F.	Pounds.
.....	.....	Expansion valve.....	.....	25	.....	.....
.....	.....	Drilling engine.....	.....	10	.....	.....
.....	42	Expansion valve.....	.....	10	(a)	(a)
.....	-6 to -17	2-stage expansion engine.....	.....	64	-40	10
.....	20 to -7	do.....	.....	30	.....	5
.....	.....	do.....	.....	30	.....	15
.....	.....	1-stage expansion engine.....	.....	30	.....	.....
.....	10	do.....	-40	15	.....	.....
.....	.....	do.....	.....	12	.....	.....
.....	40	do.....	-20	25	.....	.....
.....	50	do.....	.....	14	.....	.....
.....	.....	do.....	(b)	.....	.....	.....
.....	40	do.....	32	20	.....	.....
.....	.....	do.....	.....	55	.....	.....
.....	.....	do.....	32	.....	.....	.....
.....	.....	Expansion valve.....	.....	.....	.....	.....
.....	65	2-stage expansion engine.....	.....	.....	-30	10
.....	-30	do.....	.....	60	-12	5
.....	.....	Expansion valve.....	.....	.....	.....	.....
.....	.....	do.....	.....	.....	.....	.....
.....	38	1-stage expansion engine.....	24	.....	.....	.....
.....	40	do.....	37	10	.....	.....
.....	66	do.....	30	.....	.....	.....
.....	60	Expansion valve.....	.....	.....	.....	.....

a Changed to expansion engine.

b Vacuum.

METHODS OF EXPANSION.

At many plants the gas after treatment in high-pressure water-cooled coils and accumulator tanks is further cooled, still at maximum pressure, in heat interchangers or double-pipe condensers by expanded gas. Two methods are used to obtain low temperatures

by the expansion of gas, (1) expanding the gas through opening or valve to a lower pressure, thus producing the absorption of heat, and (2) expanding the gas adiabatically in the pistons of a steam power unit, such as a compressor, pump, or engine. Table 4 gives methods of expansion used at plants and also temperatures and pressures of the gas at the different stages of expansion and cooling.

EXPANSION THROUGH AN ORIFICE OR VALVE.

In the first method the high-pressure gas carrying some gasoline not removed by previous treatment is passed through either the inside or outside pipe of a double-pipe heat interchanger, and the gas is expanded through a small opening, such as a $\frac{1}{2}$ -inch valve, between the pipes, thus cooling the high-pressure gas and causing the condensation of gasoline. The high pressure gas and the condensate are led to an accumulator tank, where the condensate is collected and removed. From the accumulator tank the gas passes through an expansion valve of the heat exchanger and the pressure is lowered to 10 or 15 pounds, or the pressure desired or necessary to carry the gas through the field lines. The refrigerating effect obtained by this method is surprisingly small, and although many coils using this principle for cooling have been installed, few of them lower the temperature of the high-pressure gas enough to be of material benefit. In certain standard installations one coil of this type is installed for each high-pressure unit, the inside pipe of the coil having a diameter of 3 or 4 inches, and the outside 6 or 8 inches. The length is usually approximately 80 feet, and either the straight-line or return type is used. After leaving this coil the gas is returned to the lease for use on the lease, or sold to commercial gas companies.

COILS USED IN CONJUNCTION WITH EXPANSION ENGINES.

A study of Table 5 will give the reader an idea of the great variety of types and sizes of coils used as heat exchangers or refrigerators in conjunction with expansion engines and valve expanders. The principle is the same in all types. The cold expanded gas passes through one of the pipe members of a double pipe-interchanger and the high-pressure gas from the water-cooled coils passes through the other member. At the end of the coil in which the high-pressure gas is treated, an accumulator tank or drip collects the condensed gasoline as in the water-cooled coils.

Of the plants listed in Table 5, No. 6 used the smallest size of coil to form the double-pipe coil, 2-inch pipes inside of 3-inch.^a The cooling effect in this coil is rapid, but a small quantity of moisture in the gas will tend to freeze the coil and stop the flow, necessitating

^a The $\frac{1}{2}$ -inch in 2-inch coil mentioned in Table 5 as being part of plant 11 has been abandoned and replaced by a larger double coil.

ntinual watchfulness and more or less thawing to do. This particular coil is protected to some extent from water vapor by first passing the gas through two other double coils, 4-inch pipe in 6-inch, which are cooled by the expanded gas from the small 2-inch in 3-inch coil. In the larger coils the gas is cooled only to such a temperature that the greater part of the liquid condensed is water. The cooling area varies between 0.15 square foot and 3.70 square feet per 1,000 cubic feet of gas treated, and averages 0.563 square foot.

TABLE 5.—Data on double-pipe coils or heat exchangers used at various plants.

Plant No.	Type of coil or exchanger.	Number of coils.	Size of pipe.			Length of single coil.	Total length of coil.	Radiating area.	
			Number of pipes.	Inside diameter.	Outside diameter.			Total.	Per 1,000 cubic feet of gas treated daily.
				Inches.	Inches.	Feet.	Feet.	Sq. ft.	Sq. ft.
.....	Tubular.....	2	50	2	36	18	940	0.940	
.....	Straight line.....	1	1	8	16	80	167	.372	
.....	do.....	2	1	8	12	60	120	.250	
.....	Return bend.....	2	1	4	6	50	200	.210	
.....	do.....	120	1	2	3	20	2,400	1,257	.590
.....	Special straight line.....	14	5	2½	12½	100	1,400	4,575	.610
.....	Straight line.....	5	1	8	12½	100	500	1,050	1.05
.....	Special.....	2	1	12½	24	40	80	262	.349
.....	Straight line.....	3	1	4	6	100	300	315	
.....	Return bend.....	96	1	1½	2	20	1,920	630	.630
.....	do.....	6	1	4	6	80	480	502	.714
.....	do.....	2	1	2½	5	80	160	105	
.....	do.....	2	1	4	6½	80	160	167	
.....	Return bend.....	2	1	4	8	90	180	190	.750
.....	do.....	2	1	3	8	80	160	130	.173
.....	Horizontal tubular.....	4	52	1½	30	16	832	326	.181
.....	Vertical tubular.....	2	72	2	30	12	1,728	900	.600
.....	do.....	1	72	2	30	12	864	450	.450
.....	Return bend.....	6	1	2	4	40	240	126	.168
.....	do.....	20	1	3	5	40	800	630	.210
.....	do.....	4	1	4	6	100	400	420	.233
.....	do.....	1	2	2	10	40	40	42	.170
.....	do.....	3	1	4	6½	80	240	189	.150
.....	do.....	12	1	4	8	40	480	500	.250
.....	do.....	4	1	4	8	40	160	167	.420
.....	do.....	4	1	4	8	40	160	167	3.70
.....	do.....	1	1	4	6	80	80	84	.330

From the 2-inch in 3-inch coil the sizes range through nearly all possible combinations up to 12½-inch inside of 24-inch. As the pipe sizes become larger, cooling is slower. The cooling effect in the last-mentioned coil is so sluggish that it is doubtful whether the coil can be considered efficient. The tubular type of heat interchangers, such as are used in plants 19, 20, and 21, either horizontal or vertical, are built in the form of a tubular boiler, the cold gas being either in the main drum shell or in the tubes. This type of interchanger has not been as satisfactory as some of the double-pipe coils.

It seems that the length of time and the necessary intimate contact between the gas and the tube surfaces is not obtained, and radiation is incomplete, the high-pressure gas being discharged at too high and the expanded gas at too low a temperature. Both the high pressure and the expanded gas is thought to follow channels through the drum

and tubes and form eddies or dead spaces, leaving some parts of the tubes and shell inactive. In this type of interchanger a series of baffles in both the tubes and shell might give the desired result, as has been done in refinery practice. This type of cooler is used at a number of plants as a water condenser and as a unit in conjunction with double-pipe coils of smaller size.

The coil used at plant 7 (see Table 5 and fig. 7) is of special straight-line construction, consisting of five 2½-inch pipes inside of a 12½-inch casing 100 feet long. This type of interchanger is not uncommon in refinery practice, being used for the interchange of heat between oil coming from and going to stills, but in the compression plant industry its adaptation is unique. There are 14 units of this type in the entire battery. The high-pressure gas from the water-cooled coils is divided by a header and passes in parallel through the

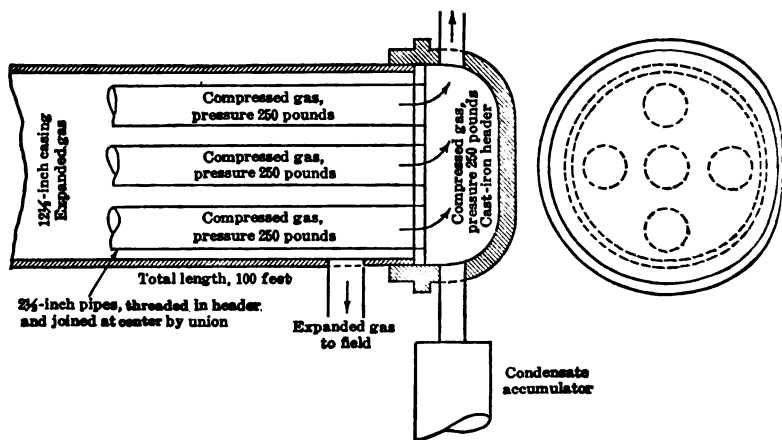


FIGURE 7.—Sections of special straight-line double coil.

2½-inch pipes of four of the units, at the end of which it is collected by a header, and again divided in the same way, passing in parallel through the 2½-inch pipes of the remaining 10 units of the battery of 14. At the end of each unit a drip (see fig. 7) collects the condensate formed.

From the discharge header at the end of the group of 10 exchangers the gas goes directly to the expansion engine. The engine exhaust or low-pressure cold gas, is returned to the 10 interchangers, passing through them in parallel in the 12½-inch shell or outside pipe counter current to the high-pressure gas. After passing through the 10 units the gas is collected in one main or header and is again divided and passes in parallel through the outside casings of the other four units again countercurrent to the high-pressure gas.

By using the 14 interchangers in two sets or batteries the gas is cooled in two stages, and by the counterflow system the coldest expanded gas is brought into contact with the coldest high-pressure

as, thus making a gradual and complete interchange of heat. The expanded gas, on leaving the battery of four coils, has been raised to approximately the temperature of the high-pressure gas from the water-cooled coils, and the high-pressure gas traversing the inside pipes is brought to the lowest possible temperature by being circulated in contact with the coldest expanded gas after it has radiated considerable portion of its heat to the partly warmed, expanded gas in the unit of four interchangers. Of the total plant production 0.4 per cent is credited to this system of cooling. These coils are not protected by a building, but are set well above the ground and housed in wooden boxes filled with sawdust, which covers the outer pipe fully 12 inches on all sides.

Plates VIII, A, and IX show views of the coils and expansion sets taken at a plant which the writer was fortunate enough to visit shortly after the installation of the expansion engine and before the work insulation of the pipes had been completed.

INCREASE IN PRODUCTION DUE TO COOLING BY EXPANSION.

In Table 6 are recorded the percentages of total production and the gravities, in °B., of the fractions of condensate collected at the different stages in accumulator tanks in plants using expansion engines and keeping records of such data. The table shows that the percentage of condensate credited to expansion units varies between 10 and 50 per cent, except at plant 76, at which all of the condensate is collected in the accumulator tank after the cooling by expanded gas is completed. This case was cited before, and is undoubtedly due to the fact that the gas is forced to travel upward through the water-cooled coils, whereas the natural flow of any condensate formed would be downward. Apparently the condensate is absorbed by the gas and precipitated later in the double-pipe interchangers cooled by expanded gas.

TABLE 6.—Percentages and gravities of condensate collected in various accumulator tanks in plants using expansion engines.

Plant No.	Condensate produced from—					
	Low-pressure coil.		High-pressure coil.		Expansion coil.	
	Per cent.	Gravity, °B.	Per cent.	Gravity, °B.	Per cent.	Gravity, °B.
3.....	33		60	79	7	95
4.....	15		60		25	
6.....	17.6	63.8	32.7	78	a 49.7	96
7.....	24.6	60	65	65	10.4	
9.....	26	60	42	80	22	90
1.....		67		84		93
7.....	30	57	50	71	20	80
2.....					10-15	96
3.....	40	70	35	80	25	100
6.....					a 100	76-82

a No condensate in water-cooled coils.

FIELDS IN WHICH EXPANSION UNITS ARE USED.

In the eastern fields, where much of the gas treated contains or no fixed or true gases, being almost entirely composed of the higher hydrocarbons, the use of extremely low temperatures of little or no benefit, and expansion engines and coils have in any plant known to the writer, been installed.

Mid-Continent practice, taken as a whole, does not include expansion engines as a part of the usual installation; expansion, however, being adopted by some operators building new plants at the present time as a part of the original plant design. Two plants (Nos. 32 and 33) visited by the writer in Oklahoma had expansion engines and coils in service, both being in the Glenn production. Operators of these plants stated that of the total production 50 per cent was directly due to cooling by gas expanded in expansion cylinders, as shown in Table 6. The cooling area of the double heat interchangers used in the two plants averages 0.22 square feet per 1,000 cubic feet of gas treated, which is less than one-third the average area used in California practice.

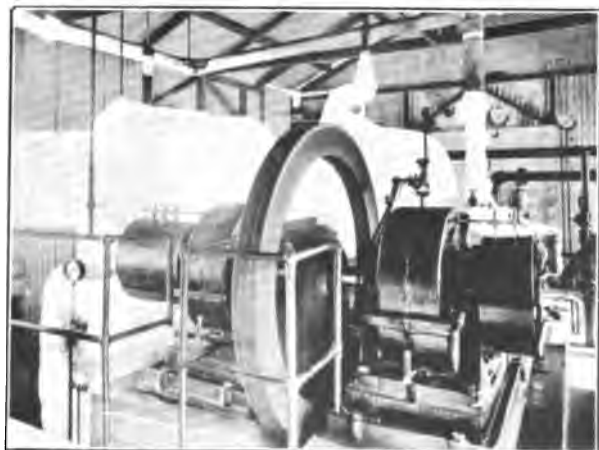
In the Caddo, Louisiana, field one company operating three expansion plants uses expansion units and coils in each plant.

EXPANSION ENGINES IN CALIFORNIA FIELDS.

The widest range of development in the installation of expansion engines and the use of expansion engines is in California fields. At plants 3, 4, 6, 7, 9, 11, and 17 in the various California fields 50 per cent of the total production is from expansion units, as shown in Table 6. It is generally figured in these fields that 25 per cent of the production is due to the expansion treatment. A plant in the Fullerton field treating 2,500,000 cubic feet of gas daily produced 3,000 to 3,200 gallons of condensate with a gravity of 72° B. When the expansion unit was put into operation. The expansion increased the daily production to between 4,000 and 4,300 gallons of condensate with a gravity of 80° to 84° B., or about 25 per cent of the total yield. The radiating areas in the heat exchangers in California plants (see Table 6, plants 1 to 21) vary from 0.20 to 0.25 square feet per 1,000 cubic feet of gas treated daily. A radiating area large enough to warm the cold or expanded gas to the temperature, as nearly as practicable, of the high-pressure gas from the water-cooled coils is all that is necessary, because any further increase in cooling surface, the two gases being brought to approximately the same temperature, has no effect. The proper radiating area for each 1,000 cubic feet of gas to be treated daily is a factor that can be obtained only by experiment at each plant, unless the operator has had experience in the particular field and with the particular

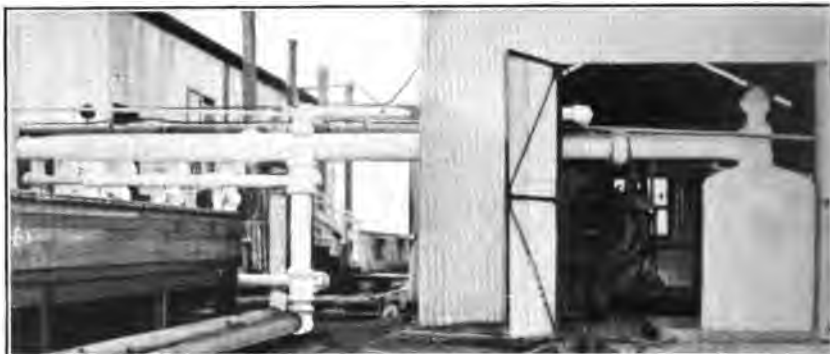


A. END OF HORIZONTAL TUBULAR COOLER, TYPE USED IN PLANTS 19, 20, AND 21.

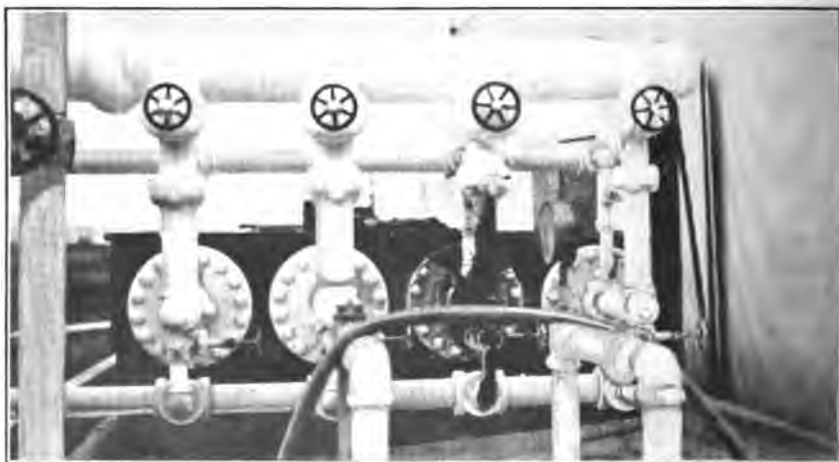


B. TWO-STAGE EXPANSION ENGINE IN COMPRESSION PLANT.

Note ice on accumulator tank and piping.



A. EXPANSION-EXHAUST ACCUMULATOR TANK AND PIPING. TANKS SHOW 2-INCH COATING OF FROST. TEMPERATURE OF GAS WAS BELOW 0° F.



B. END OF DOUBLE-PIPE COILS AND INTAKE MANIFOLD FOR EXPANDED GAS.



C. HEADER FOR EXPANDED GAS. CORK INSULATED INTAKE. PIPES EXPOSED TO AIR.

o be treated, or has data on the area used and the efficiency obtained at another plant already at work in the same field and treating the same gas.

TEMPERATURES OBTAINED FROM GAS EXPANSION.

The temperatures produced by heat exchange on high-pressure gas vary in practice from -17° to $+65^{\circ}$ F., or between 75° below and 20° F. below atmospheric temperature, as shown in Table 4 (p. 41). The best temperature to use in a given plant depends, as does the ultimate high pressure used, on the characteristics of the gas and the product desired, also on the efficiency of extraction and temperature previously obtained in the water-cooled coils. As the condensation of vapors depends on both temperature and pressure, in accordance with the physical laws of gases, at a given pressure there is some critical temperature below which it is useless to cool the gas, as Burrell^a has demonstrated in the laboratory method of determining the quantity of condensable vapors in any given gas. The method of laboratory test uses only atmospheric (14.4 pounds at an elevation of 600 feet) pressure, and the extremely low temperature of 115° C. below zero, which is equal to 175° F. below zero.

At this temperature all of the propane and the butane are liquefied, which in compression practice is neither practicable nor desirable, because these two hydrocarbons are so volatile at atmospheric temperatures and pressures as cause them to weather out of plant products to a large extent, if not entirely. As a portion of each condensable hydrocarbon is precipitated and taken out of the gas, the pressure necessary to condense the remaining portion at a constant temperature rises, in accordance with the law of partial pressures. Or, with the pressure remaining constant, the temperature must be reduced to precipitate the remaining portion of that particular vapor fraction. Conversely, if at a given pressure any condensable constituent would be entirely precipitated when the gas reached the critical temperature of that fraction, the composition of the gas would be simplified and the precipitation of the other condensable fractions more complete at the same pressure. This has been demonstrated in practice in a plant using a maximum pressure of 150 pounds, and a temperature as low as 10° F. below zero at the discharge of the high-pressure coil, which was cooled by expanded gas. (See Pl. IX, A.) The condensate collected in the tank at the end of the coil contained more than 1 per cent of water; a small percentage of water was also found with the lightest condensate precipitated at the exhaust of the second stage of the expansion engine. (See Pl. VIII, B.) If water vapor is retained through all of the steps of compression and

^a Burrell, G. A., and Jones, G. W., *Methods of testing natural gas for gasoline content*: Tech. Paper, 87, Bureau of Mines, 1916, p. 26.

cooling, as demonstrated in the plant just cited, it is probable that portions of all the hydrocarbon fractions are also. The points to be determined in any plant are the quantity of such vapors being lost and the temperature necessary to condense them as well as the value of the product and the cost of an installation to obtain the required results.

The value of the condensate obtained will depend on the quantity that can be marketed, and if excessive pressures are used, the product may be so light and volatile as to be of little value. A proper relation between pressure and temperature will in all instances yield the maximum marketable condensate from any given gas, and this relation can be found only by trials and tests made at each plant. In the plant cited above, the product obtained in the accumulator at the expansion engine exhaust had a gravity of 105° B., and probably consisted principally of butane, with small proportions of the other higher hydrocarbons and of water. The gas in this accumulator had a temperature of 40° F. below zero and a pressure of 10 pounds, as the result of the two stages of expansion. It was found that in the expansion cylinder of the engine, the gas had reached a temperature lower than 100° F. below zero before being exhausted. The quick rise in the temperature of the gas between the cylinder and the tank, which was connected to the exhaust by a short insulated pipe, is probably due to two factors, radiation from the cylinder walls and the latent heat of vapors given out on condensation.

In a plant in Oklahoma, in experimenting with expansion units, it was found that the desired low temperatures could not be obtained. So little vapor was precipitated in the coils ahead of the expansion unit that in expanding the gas the latent heat given up by the condensing vapors immediately reheated the expanding gas to 20° F. The remedy for a condition of this kind would necessarily have to be found either in the pressure or water cooling to which the gas was being subjected.

TEMPERATURE AND PRESSURE CHANGES IN A COMPRESSION PLANT.

Figure 8 shows diagrammatically the changes in both pressure and temperature to which gas is subjected in average compression-plant practice. The vertical coordinates show temperatures in degrees Fahrenheit for the solid line or temperature curve, and pressures in pounds per square inch for the dotted or pressure curve. The horizontal coordinates represent the different stages of treatment at which the changes of pressure and temperature occur.

FLOW SHEET OF A COMPRESSION PLANT.

Figure 9 shows the gas flow diagram of a 2-stage compression plant using single-stage expansion, connected with two sets of expanded-gas cooled coils in series. The gas intakes and discharges of the com-

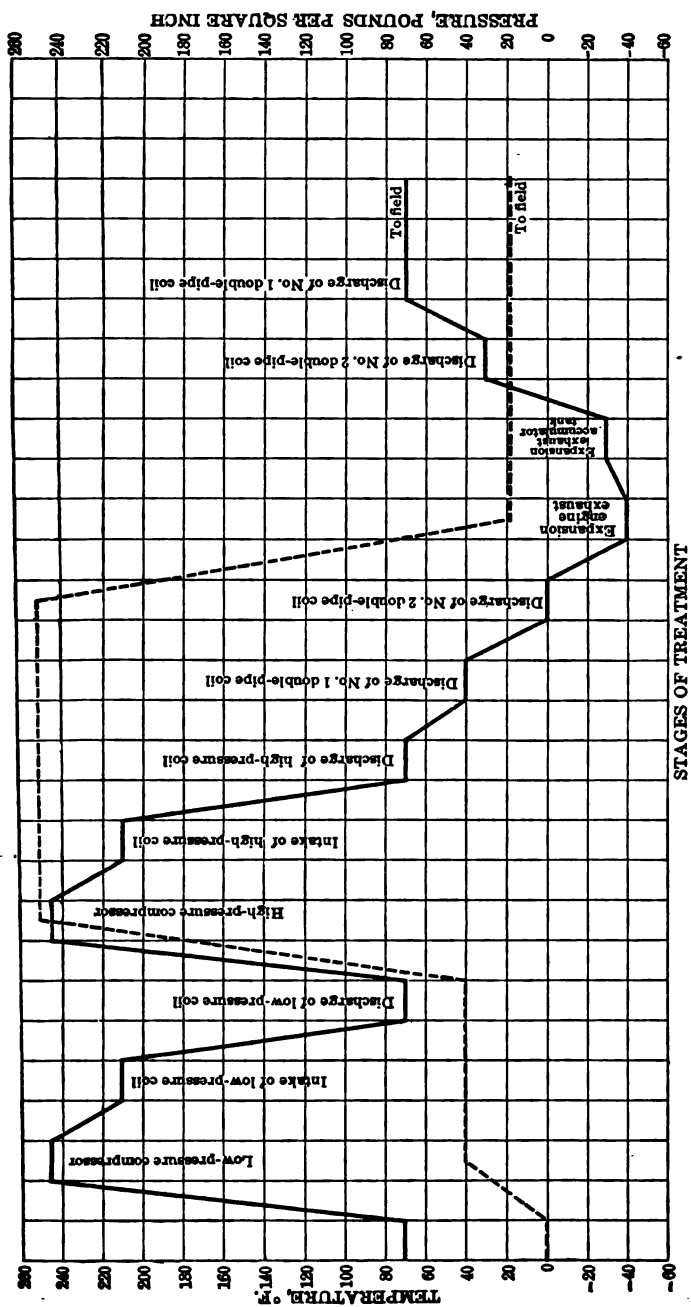


FIGURE 8.—Diagram showing the changes in temperature and pressure of gas in compression-plant practice. Dotted line is pressure curve, solid line is temperature curve.

pressors and the water-cooled coils are shown connected in manifold, this system of connections being the most flexible. With valves properly placed, any unit, part of a unit, or coil may be cut out for

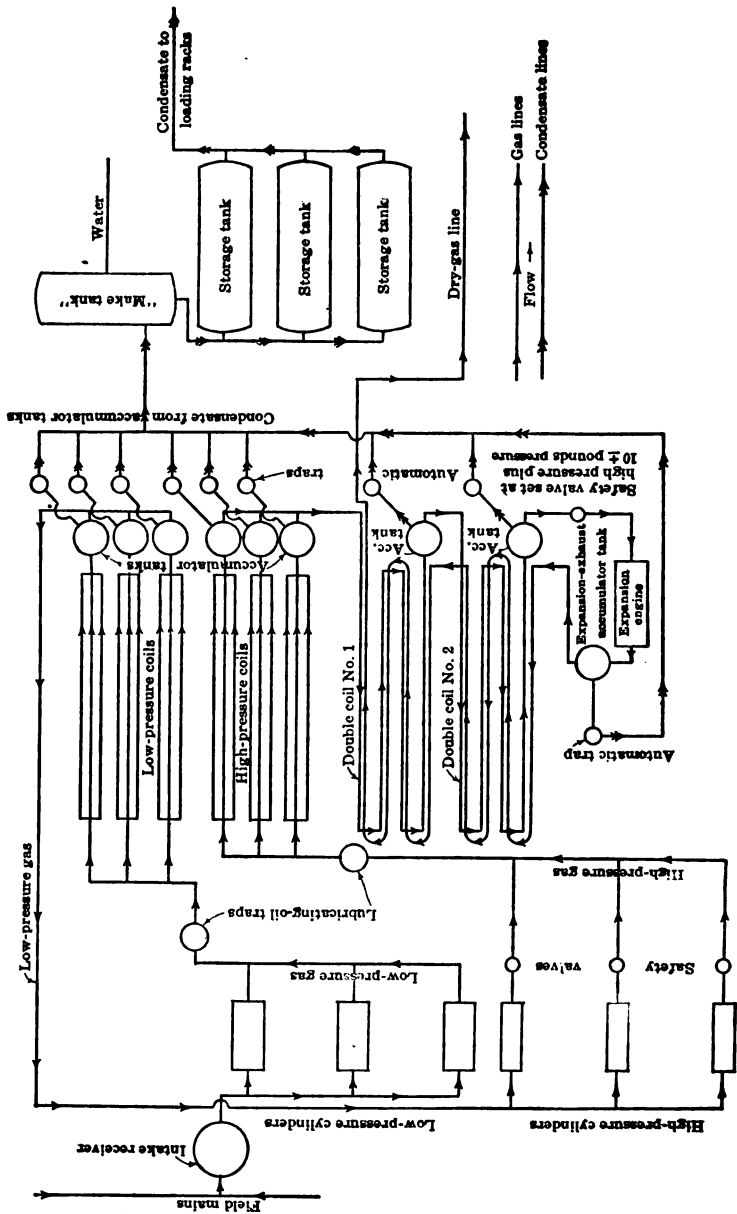
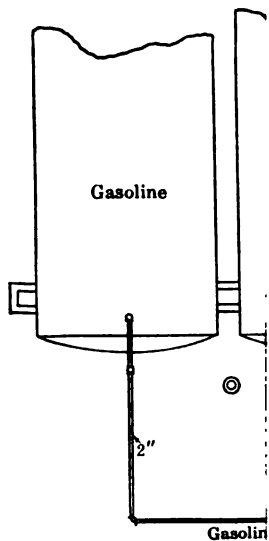


FIGURE 9.—Flow sheet of compression plant using 2-stage compression and single-stage expansion.

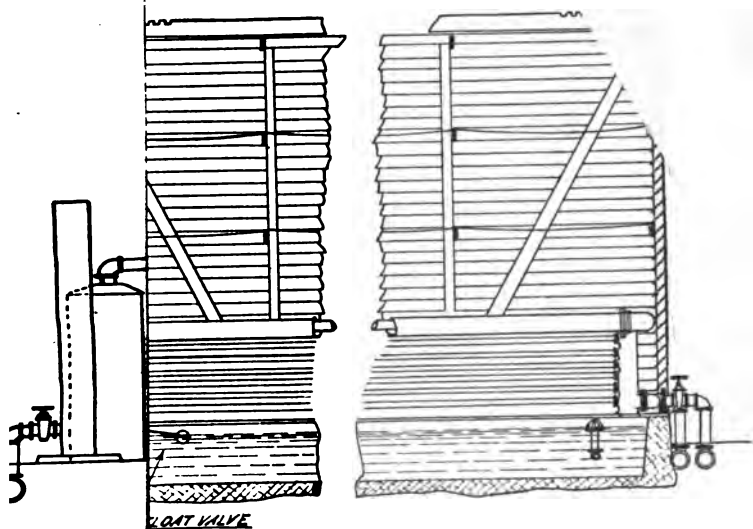
inspection or repairs without shutting down any other part or stopping plant operations, the work of the inactive unit being taken up by a small overload on the other units.

BUREAU OF MINES



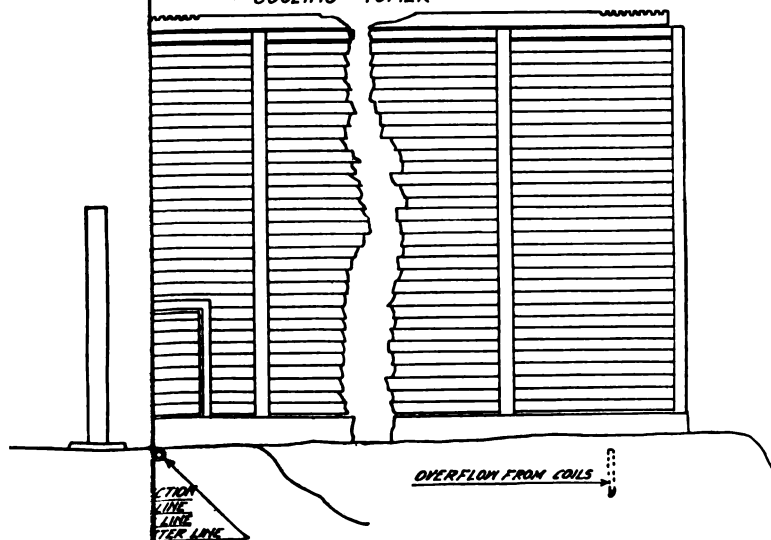


REAU OF M



FLOAT VALVE

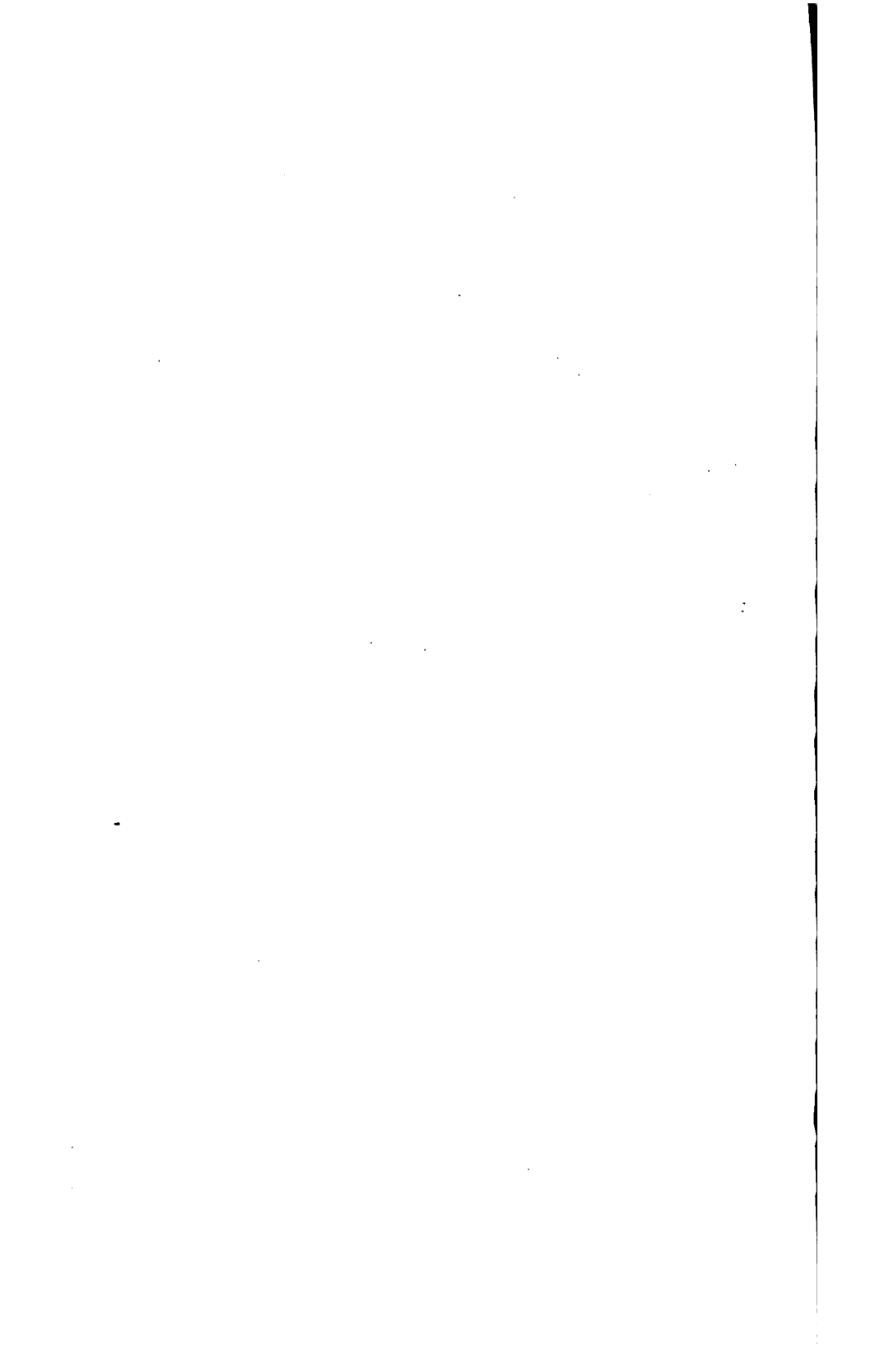
COOLING TOWER



OVERFLOW FROM COILS

WATER LINE
WATER LINE

IN PLATE X.



A single-stage expansion engine is shown connected with two double-pipe coils in series; if two stages of expansion were being used each of the double-pipe coils would use the gas expanded in one stage and be so connected that the gas from coil No. 1, using first-stage expanded gas, would return to the second-stage expansion cylinder, from which it would be returned to coil No. 2 to further cool the high-pressure gas.

Plates X and XI show plans and elevations of a typical direct-connected compressor plant. The low-pressure and the high-pressure cylinders are operated independently by separate gas engines.

USE OF POWER DEVELOPED BY GAS EXPANSION.

At all plants where expansion units are used, the development of power by the expansion of the gas has been a secondary consideration. In a number of plants power is developed only to give resistance to the expanding gas, as in a plant using a pump under a back pressure of 150 pounds, and in another plant compressing air to 40-pound pressure, only to release it to the atmosphere through a small valve set to hold the required back pressure on the natural gas.

In plant 17 the compressor end of the expansion unit holds a vacuum on the double-pipe coil and on the exhaust of the power cylinder, and delivers the gas at a pressure sufficient to return it to the lease. (See Pl. XII, A.) This use of the power developed is not uncommon, although usually the compressor suction is above atmospheric pressure. At plant 76 the power developed from expanding the gas in two single-stage cylinders working in duplex is used to compress air in two stages to a pressure of 85 pounds, to be used in air lifts in pumping oil wells. Other plants use the power generated by single-stage expansion units, as in the tandem compressor, or by two-stage expansion units, as in the cross-compound machines, to drive one of the two-stage compressor units connected in parallel with the other compression cylinders, both at the intake and the discharge. A compressor used in this way may, as at plants 6 and 14, take gas from and deliver it to the manifolds used for the intake and discharge of the other compression units.

EFFICIENCY OF EXPANSION UNITS.

The amount of power developed in an expansion engine as compared with the amount used in compression is very low, probably not more than 5 or 10 per cent in average plants. This condition is to be expected because of the energy loss through dissipation of heat, the consumption of power in operating the piston and valve in the expansion cylinder, and the reduction in pressure through losses of gas and vapor by condensation and leakage during transmission through pipes and cooling systems.

An exceptional instance of power developed in an expansion was noted at a California plant. Tests showed that between 35 per cent of the power used to compress the gas was developed in the expansion engine, which used in its power cylinders a gas compressed in two stages of expansion, with heating between the two expansion cylinders. The plant compressed 1,900 cubic feet of gas per minute, of which 690 cubic feet was compressed at the compressor end of the expansion engine.

The gas entering the high-pressure cylinder of the expansion engine at a pressure of 250 pounds had a temperature of 5° F. below zero; the discharge pressure was 50 pounds. The gas was passed through double-pipe coils and heated to 50° F. before entering the low-pressure power cylinder. From this cylinder the gas was exhausted at a pressure of 10 pounds and a temperature of 5° F. below zero. The gas from the second expansion exhaust was used for cooling the high-pressure gas, and was then discharged from the plant at 57° F. A measurement of the temperature in the low-pressure expansion cylinder indicated a temperature of 5° F. below zero.

If a more efficient return of power were made an object, more power could be developed by heating the high-pressure gas before it leaves the double-pipe interchanger, in an interchanger with which the hot gas from the high and the low pressure compression cylinders is heated. If desirable the gas could be further heated in a double-pipe interchanger by the exhaust from the power cylinder of the gas engine. This could be accomplished in a tubular interchanger such as is used for preheating boiler feed water with exhaust gases.

Heating the compressed gas before it enters the valve chest of the expansion cylinder would also tend to reduce freezing at that point, thus reducing the power used in moving the valve mechanism.

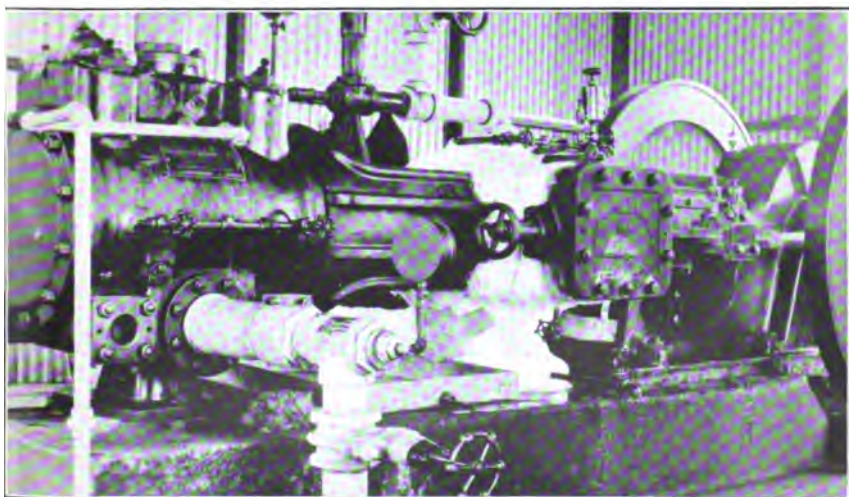
To obtain as low temperatures of the expanded gas, with minimum power as without preheating, more power would have to be developed and used by the expansion unit. This could be accomplished by adding expansion units, by increasing the load, or by running the compressor faster at the same pressure, thus increasing the volume of gas compressed in a given unit of time.

EXPANSION FOR POWER ALONE.

In expanding compressed gas for power purposes only, as is done for refrigeration, as is contemplated in an eastern plant, preheating the gases by either the hot compressed gas or the engine exhaust would be necessary in order to make the installation a commercial success. Using a relatively small quantity of gas at a low temperature (60° F.) would hardly pay in power delivered, as compared with a gas engine using gas worth 15 cents or less per 1,000 cubic feet.



A. LOADING RACK FOR TANK CARS AT BLENDING STATION.



B. SINGLE-STAGE COMPRESSOR USED AS EXPANSION ENGINE PUMPING GAS TO FIELD AT 60 POUNDS PRESSURE.



C. COMPRESSION PLANT, SHOWING HORIZONTAL TYPE OF "MAKE" TANKS IN MIDDLE FOREGROUND, AND OF ACCUMULATOR TANKS, AT RIGHT.

USES MADE OF TREATED GAS.

With the passage of the gas through the coils of the expansion unit, the treatment for recovery of gasoline is finished.

Gas used for power to run the compression plant, either in gas engines or under boilers, is universally taken from the treated gas, the rest being returned to the lease or pumped into the lines of a commercial gas company. The lease or contract usually stipulates that gas used for power in the compression plant is to be taken from the treated gas at no cost to the lessee.

GAS USED PER HORSEPOWER IN COMPRESSION UNITS.

The quantity of gas necessary to operate a gas engine will vary from 9 to 18 cubic feet per horsepower-hour, depending on the size, type, and age of the engine and the care given it. Boilers in a steam plant require 40 to 120 feet per horsepower hour. A plant having six 80-horsepower, direct-connected, horizontal, 2-cycle gas engines used between 12 and 14 feet. The engines had been in service two years and had been well cared for. The large 450 to 1,100 horsepower, horizontal, direct-connected, tandem, double-acting, 4-cycle units will use as little as 9 feet and the 150 to 200 horsepower, vertical, 4-cylinder, 4-cycle, belted units will use 10 to 14 feet per horsepower hour.

Olliphant^a gives the following table showing the average amount of natural gas required to operate gas engines or to supply a steam-engine plant using natural gas as fuel under the boilers in cubic feet per indicated horsepower hour:

Cubic feet of natural gas required per horsepower-hour to drive a gas engine or steam plant.

	Cu. ft.
Large gas engine, highest type.....	9
Ordinary gas engine.....	13
Triple-expansion condensing steam engine.....	16
Double-expansion condensing steam engine.....	20
Single-cylinder steam engine with cut-off.....	40
Ordinary high-pressure steam engine without cut-off.....	80
Ordinary oil-well pumping steam engine.....	130

From 10 to 12 cubic feet of air is necessary for the complete combustion of 1 cubic foot of natural gas.

PERCENTAGE OF GAS RETURNED AFTER CONDENSATE AND GAS USED FOR POWER IS DEDUCTED.

The reduction in the volume of the gas from treatment by the compression process is unaccountably large. As has been stated, in treating gas from old wells that have been gas-pumped for years and are held at high vacuums, practically all of the gas disappears in one stage or another of the treatment, often not enough being left to run the engines.

^a Olliphant, F. H., Catalogue of metric metal works, 1914, p. 42.

Gas produced under natural pressure in the newer fields contained a much higher percentage of fixed gases, hence the quantity of residual gas, after condensate and gas used for power have been deducted, reaches 70, or, in some plants, it is claimed, 80 per cent of the total wet gas entering the plant. Exact figures on the quantities of residual gas are seldom kept in compression plants, it being a matter of little importance in most fields. It appears, however, from the figures that the writer was able to obtain that in plants treating gas yielding $1\frac{1}{2}$ to 2 gallons of condensate per 1,000 cubic feet the net amount of gas left after treatment and deducting gas used as fuel, would average approximately 66 per cent of the total amount entering the plant. As the gas being treated increased in gasoline content the quantity of residual gas became less and less until it was not sufficient to furnish power for compression.

GAS USED FOR POWER AND TO FORM CONDENSATE.

Between 10 and 15 per cent of the total quantity of gas treated is required for power purposes, depending on the type and the efficiency of the engines driving the compressors. Burrell^a states that it takes, on an average, 35 cubic feet of vapor to produce 1 gallon of condensate, or 3.5 per cent for each gallon produced from 1,000 cubic feet of gas, or if 3 gallons of unweathered product is made it will account for 10.5 per cent of the total gas entering the plant. The condensation of water vapor during the treatment will also account for a certain percentage of the total volume. The gas and vapor unaccounted for in the ways noted must be lost by leakage in pipes and machines during the various stages of plant operation, and by weathering of light fractions.

FOREIGN CONSTITUENTS IN NATURAL GAS.

AIR.

Besides water vapor, a number of gases not of the hydrocarbon groups are often found in natural gas. Air, if present, may be a constituent of gas from wells under high vacuums, but is usually due to inward leakage, either in the well casing or in lines transmitting the gas to the plant. At a plant visited in the Shallow pool of Oklahoma, the writer was informed that the gas being treated contained 30 per cent air. The area from which the gas was being drawn covered 12 square miles, making the use of long gathering lines and many vacuum pumps necessary, which probably accounts for the extremely high air content.

^a Burrell, G. A., Seibert, F. M., and Oberfell, G. G., The condensation of gasoline from natural gas Bull. 88, Bureau of Mines, 1915, p. 60.

WATER VAPOR.

Air always carries more or less water vapor with it, and this fact may account for part of the water precipitated with condensate. As most oils carry some water with them from the oil-bearing formations, it is natural to believe that some water vapor from this source would be carried into the gas, especially when the wells are being gas-pumped and low pressures maintained. The temperature of the oil and water under ground would also tend to allow water vapor to form and be held in the gas. In one instance, the oil coming from a certain well also producing gas had a temperature of 150° F. in the flow lines.

A California plant treating 2,500,000 cubic feet of gas daily produced water with the condensate at various points as follows:

Gallons of water drained from various points at California plant in 24 hours.

	Gallons.
From low-pressure accumulator.....	200
From high-pressure accumulator.....	50
From final double-pipe coil.....	25
From storage tank.....	65
Total.....	340

This quantity of water was equal to between 5 and 6 per cent of the condensate produced.

CARBON DIOXIDE.

The proportion of carbon dioxide in natural gas used in compression plants varies widely. As much as 30 per cent has been found in both the Mid-Continent and California fields. So large a proportion is unusual, but percentages up to 10 are not uncommon in California fields, and in some districts in Oklahoma.

Nitrogen is found in the natural gas in some districts, as noted by Burrell,^a but was not found in gas fields visited and sampled by the writer, except as introduced into the gas with air.

SULPHUR COMPOUNDS.

Hydrogen sulphide or other gaseous sulphur compounds, usually called "sulphur gas," is found in many of the fields producing casing-head gas. However, only the gas from small areas of these fields contains sulphur in such quantities as to be a decidedly detrimental factor in treatment of gas for its gasoline content.

Plants in the southern Illinois field are troubled by sulphur compounds more generally than those in any other district as a whole. A plant in the Santa Maria and one in the Salt Lake field in California report sulphur trouble, but such contamination is local and is not characteristic of those fields as a whole.

^a Burrell, G. A., Seibert, F. M., and Oberfell, G. G., The condensation of gasoline from natural gas: Bull. 88, Bureau of Mines, 1915, pp. 21-22.

GENERAL EFFECTS ON COMPRESSION TREATMENT.

The gases named, with the exception of hydrogen sulphide, are inert chemically through all the stages of the compression process. Physically they affect plant practice in two ways. They cut down the volume of productive gas treated or absorb power for which no return is possible; they complicate the problem of partial pressures by requiring higher pressures for the gas as a whole in order to bring any one of the condensable fractions to its critical pressure, thus again necessitating more power.

EFFECTS OF SULPHUR AND METHODS OF REMOVAL.

In the Lawrenceville district of southern Illinois the proportion of sulphur in the natural gas is so large as to be a decided detriment to treatment by compression. Beside destroying the pipes in cooling coils, so much of the hydrogen sulphide is dissolved in the condensate, either as a gas or as a liquid, that resort is had to steam distilling in order to free the condensate from this objectionable content. The odor of even small proportions is noticeable, making the product unsalable, and such gasoline, if used in motors, will attack the pistons and cylinders, causing pitting and roughness. By use of the steam stills in that district between one-third and one-half of the total plant product is lost as noncondensable vapor passing through the cooling coils after the stills.

The two California plants, mentioned previously, report no trouble with sulphur in the condensate, but do have trouble from the sulphur gas attacking and eating out cooling coils. At the plant in the Salt Lake field 2-inch steel pipes will often be eaten through, particularly at a low point in the coil, in 3 or 4 months. The plant in the Santa Maria field found that 2-inch steel pipe, costing 12 cents per foot (May, 1916), in the cooling towers lasted 6 months, and that wrought-iron pipes, costing 19 cents per foot at that time, lasted 13 months or more.

No compressor or engine trouble traceable to hydrogen sulphide gas was reported at any of the above plants, possibly because of the film of lubricating oil constantly protecting the pistons and cylinders.

The elimination of sulphur gas has long been a part of the treatment for purifying manufactured or artificial gas. The artificial gas made from coal or oil is passed through a scrubber containing iron oxide (common hematite iron ore). A chemical reaction takes place, the sulphur uniting with the iron to form iron sulphide, which is a solid at normal temperatures, thus removing the sulphur from the gas. When the iron becomes slow in its action, or so largely converted to the sulphide as to be inefficient in removing the sulphur, it is discharged and a fresh charge placed in the scrubber. The scrubbers are generally operated in pairs to allow one to be cut out

during periods of cleaning and charging. The discharged iron ore is thrown out on the ground, where it is oxidized by the action of the sun and the atmosphere, and again used as a fresh charge for the scrubbers.

The sulphur compounds originating in gas act chemically as an acid in much the same way as the acid fumes that are carried in still vapors in oil refining.

An eastern refinery which compresses the uncondensed still vapors and gases to further remove condensable fractions uses a series of water and caustic washes in scrubbing tanks to remove acid impurities, as described on page 68.

To overcome the action of sulphur gas which was eating out the high-pressure coils of a compression plant, Mr. D. L. Newton, general superintendent of the Hurley Smith Gasoline Co., of Los Angeles, Cal., designed and successfully operated a scrubber and cooler combined which removed the objectionable gases and also took the place of the high-pressure water-cooled coils.

Figure 10 shows the general design and method of operation of the scrubber. After this treatment the gas was refrigerated in double-pipe coils of usual construction without causing their destruction or forming incrustations of sulphur compounds.

The following data, regarding the operation of the scrubber, was also kindly furnished by Mr. Newton:

Data on scrubber for removing sulphur.

Capacity, 300,000 cubic feet per day at a pressure of 250 pounds.

Temperature of gas entering scrubber, 190° F.

Temperature of gas leaving scrubber, 78° F.

Temperature of water entering scrubber, 72° F.

Temperature of water leaving scrubber, 78° F.

Volume of water used per 24 hours, 15,000 gallons.

The water used in the scrubber, after being automatically trapped from the separator, was returned to the top of the cooling tower for cooling in the usual way. Owing to aeration and the lowered pressure, the greater part of the sulphur gas passed off into the air, the cooled water being returned to the scrubber by a pump at a pressure slightly higher than that at which the gas entered the scrubber.

CONDENSATE.

LINE DRIP.

The first condensate produced in treating gas by compression is the small quantity of rather heavy and often discolored naphtha accumulating in the pipe-line drips. After this condensate has been collected and cleaned by filtering or distilling it is mixed with the balance of the plant product, giving the mixture a lower gravity and vapor tension and helping to stabilize the "wild" condensate from other parts of the plant.

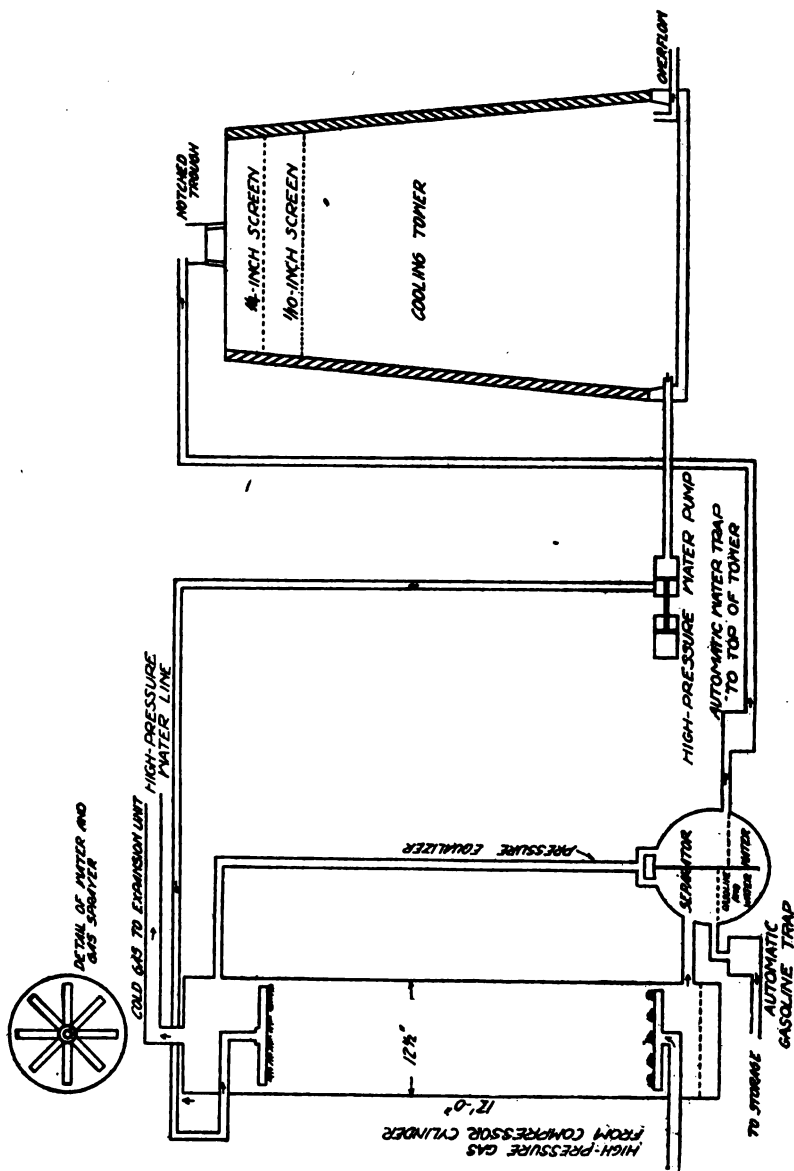


FIGURE 10.—Scrubber used to cool gas and remove sulphur compounds.

CONDENSATE FROM LOW-PRESSURE COILS.

The second condensate is that collected in the low-pressure accumulator tanks; its proportion to the whole product varies between nothing and 50 per cent, and in average plant practice between 10 and 30 per cent. The gravity varies around 60° B. and the vapor tension between 1 and 3 pounds. Such condensate makes an ideal motor fuel just as it comes from the coils, but is usually mixed before leaving the plant with the other products either in "make tanks" or in storage tanks, having the same tendency as the line drip to improve the product as a whole.

The following distillation represents approximately an average first-stage condensate as produced in California practice:

Results of fractional distillation of first-compression naphtha (condensate).

[Analyst, Paul W. Prutzman.]

Still charged with 500 c. c., at 62° B.; started over at 106° F.

Cut No.	Amount of cut.	Final temper- ature.	Gravity of cut.	Per cent.
	c. c.	° F.	° B.	
1.....	50	174	76.8	10
2.....	50	192	71.8	10
3.....	50	206	66.5	10
4.....	50	218	63.1	10
5.....	50	228	60.8	10
6.....	50	241	58.4	10
7.....	50	254	56.5	10
8.....	50	272	54.6	10
9.....	50	312	51.4	10
.....	16	352	.....	.....

Total amount distilled off and collected, 466 c. c.; final temperature, 352° F. Loss, 8 per cent.

Eastern or Mid-Continent products with these end points would have a specific gravity between 5° and 9° B. higher, but the sample distilled is fairly representative of the first-stage product of two-stage plants.

CONDENSATE FROM HIGH-PRESSURE COILS.

Next in the series of condensates collected is that obtained from the gas under the maximum pressure used in any given plant and at temperatures developed by water cooling.

In average plant practice the condensate precipitated and collected at this point represents the principal bulk of the total recovery, seldom being less than 30 per cent of the total product even in plants using expansion units, and at times reaching 100 per cent, as in all single-stage practice and in some two-stage installations. At plant 22, which compressed the gas to 300 pounds in two stages and cooled it to 60° F. in the high-pressure coils, all the condensate was produced at this point, the product having a gravity of 96° B.

The specific gravity of the high-stage condensate is between 65° B. and 100° B., averaging in eastern fields approximately 85° B., in Oklahoma 78° B., and in California 72° B.

As formed in the accumulator tank this condensate is "wild," owing to the absence of low-gravity fractions, to dissolved gas, and to hydrocarbons that can be held as liquids only under high pressure at the temperatures attained in the water-cooled coils. As the pressure is reduced by the automatic traps or in the transfer from accumulators to the "make" or storage tanks, the lighter fractions and dissolved gases immediately start coming off and build up pressure in the tank containing them or escape to the atmosphere. For these reasons the condensate from high-pressure accumulators is usually discharged to tanks containing the heavier fractions precipitated in other coils and is often blended in there, or before it reaches the storage tanks.

CONDENSATE FROM EXPANSION COIL.

Table 6 (p. 45) gives the gravity and percentage of this condensate as obtained in plants using expansion units. The condensate has much the same physical characteristics as the condensate from high-pressure water-cooled coils and is handled and treated in the same way.

CONDENSATE FROM EXPANSION EXHAUST.

As stated and discussed under expansion units, plant 6 collects a high-gravity (105° B.) condensate in an accumulator close-connected to the exhaust of the second-stage expansion cylinder. This condensate is stored separately and held under pressure until blended with large quantities of 48° B. naphtha.

At the plant shown in Plates VIII, A (p. 46), and IX, A (p. 47), the condensate collected in the expansion-exhaust accumulator tank is mixed with the balance of the plant product and the mixture is shipped, without blending, by auto trucks.

CONDENSABLE HYDROCARBON FRACTIONS IN NATURAL GAS.

From these data and from points previously brought out, it appears that different natural gas from different fields containing the same quantity of condensable vapors seldom contains the same percentages of the various hydrocarbon fractions entering into the composition of gasoline.

This, in part at least, explains the wide variation in the gravity and amount of product obtained under similar conditions of temperature and pressure in different plants treating gas from different parts of the same field or from different fields.

From the study made by the writer of the conditions as found in fields throughout the United States, the explanation seems to lie in

ny one, or a combination, of three conditions—the fractional composition of the gasoline content of the oil from which the gas comes, the temperature of the oil, and the pressure on the oil at the time of releasing the vapors to the gas.

Under the first condition, as demonstrated by refinery results and fractionations, it has been shown that distillates of the same gravity and the same or different end points vary widely in the content of the different fractions obtained between the same temperature limits. The oil containing only certain fractions of the light hydrocarbons can give up only these fractions to the gas, regardless of the temperature or pressure.

As the temperature of the oil varies in different fields and at different localities and depths in the same field, the factor of temperature must bear directly on the fractions of distillates contained in the gas. At constant pressures and temperatures only certain of the fractions will vaporize and be carried into the gas, leaving other fractions as liquids with the oil.

In any oil field, rock pressures decline as the supply of gas and oil is reduced. As the boiling or vaporizing temperatures of liquids are lowered by reduced pressures, this condition of lower pressures allows the less volatile, heavier fractions to vaporize if the temperature remains constant, thus adding to the gasoline content of the gas. As the rock pressure becomes low and the rate of decline so slow as to be practically stationary, and vapors no longer distill naturally from the oil left in the ground, resort is had to vacuum pumps to increase the flow of oil and gas, thus permitting the vapors to distill from the oil in the sands. Under this method is produced the gas of which the greatest proportion is condensable, as in eastern compression practice.

The widely varying conditions under which casing-head gas obtains its charge of condensable vapors, the variable content of lighter hydrocarbons in the oil in the ground, and the direct effects of the law of partial pressures on the products precipitated at the different stages in plant practice will to no small extent account for the great differences in plant practice as to pressures and temperatures used, and also for the variations in the percentage and gravity of the condensates of successive plant stages and the gravity and vapor tensions of the product of plants in different fields.

VARIATIONS IN PLANT PRODUCT.

The quantity and the gravity of condensates from different plants is shown in Table 2 (p. 29). These figures represent the average quantity and the average gravity, but both vary considerably from day to day and month to month. Many theories have been advanced to account for these variations, but none of them is satisfactory in analyzing the variations as they actually occur in plant production.

From the known effects of temperature on gas containing condensable vapors, it is reasonable to believe that atmospheric conditions, changing as they do with the seasons, explain in part the differences noticed from time to time in the yields from the different stages and in the total plant output. Many operators state that a larger proportion of condensate of higher gravity is collected in the low-stage accumulator tanks in cold weather. This same result is noticed also in the quantity and gravity of "line distillate" precipitated in gathering systems and collected in the line drips. In many plants the total production increases in winter, but this is not always true, as in plants using low temperatures, produced by expansion engines. It is often found that cold weather condenses some vapor in the gathering lines, and unless this is collected and added to the total an actual decrease in plant production results. It has been shown by several records of plant production that the yield decreases on a cold day and increases to a point well above the average on the first warm day after a period of cold weather. A plant in a hot climate on keeping records of the variations in production and attempting to determine the factors concerned, found that in general the production usually varied from day to day with the temperature, but at times varied in the opposite direction. The operators believed that the cause was to be found in a combination of atmospheric conditions, including temperature, barometric pressure, and humidity, which undoubtedly would affect evaporation and cooling of water used either in towers or sprays. To what extent these conditions control the production or account for the variations in it, it is not possible to say.

Another plant that had been treating the same quantity of gas daily from the same wells for nearly three years suddenly increased its production from 5,200 to 5,900 gallons per day, averaged over a period of one month, no changes having been made in plant practice. The operators believed that the increase was due to some change in underground conditions that permitted the gas to be enriched. Exceedingly careful records have been kept at this plant, and these show that the daily production usually varied between 100 and 300 gallons. The sudden increase of 700 gallons daily over a period of one month has not been satisfactorily accounted for. The gravity of the condensate remained constant.

Usually the gravity of the total plant product increases in cold weather, owing to the separation of part of the heavy fractions in the gathering lines and to the condensation of lighter fractions in the water-cooled coils.

It appears that a satisfactory explanation of the causes of variation in production will not be arrived at until complete records of the variations in yield and gravity of the condensate, in the tem-

temperatures and pressures used, and in atmospheric conditions are kept at different plants so these data can be studied with reference to each other and a comparison made of the results obtained at a number of plants in different fields and under different climatic conditions.

THE USE OF AMMONIA AS AN AUXILIARY COOLING AGENT.

DESCRIPTION OF PLANT IN FULLERTON FIELD.

A detailed description of plant 2, which is situated in the Fullerton, California, field follows: The casing-head gas being treated in the plant is brought from 20 oil wells through 3,500 feet of 2, 4, and 6 inch lines, 2-inch lead lines from the different wells being connected with the main gathering lines of 4 and 6 inches diameter.

The 6-inch main discharges the gas at the plant into a 6-foot by 10-foot steel receiver which also acts as a scrubber and accumulating tank for "line distillate," removing from the gas the crude oil, the condensate formed in the pipe lines, and dirt. The receiver is connected to a single-stage, 40-horsepower, noncondensing, direct-connected air compressor with 12 by 16 by 12 inch cylinders. The compressor is steam driven, rate 200 revolutions per minute, and takes steam at a pressure of 110 pounds. The compressor holds on the intake receiver a 10-inch vacuum that brings the gas through the pipe lines from the well, but is practically dissipated by friction and leakage, leaving the pressure at the wells at or near zero.

REFRIGERATION "STILLS."

Seven "stills," or coil heat interchangers are used in cooling the gas. (See fig. 11.) Each still consists of 1,260 feet of 1½-inch, extra heavy pipe coiled, with return bends, inside of a 12-inch tube 80 feet long laid at a slope of 1 inch in 10 feet, or 8 inches in all, to collect the condensate at one point, thence it is drained into storage or "make" tanks. The seven stills are parallel with one another, all draining in the same direction. Four of the stills, in which ammonia is used as the refrigerant, are insulated by about 1 foot of sawdust contained in a wooden housing about the tube; the other three coils, which treat the hot gas from the compressor, are not insulated and are exposed to the air, the hot gas flowing in the 12-inch tube and the cold gas in the 1½-inch coils.

The compressor discharges the gas at a pressure of 37 pounds and a temperature of 150° F. into stills 1 and 2, connected in parallel. These stills discharge into the outer tube of still 3, the gas from this still flowing through the outer tube of each of the other stills in succession. The dry, cold gas from still 7, in which the lowest temperature, approximately 10° F., and the final precipitation of condensate are obtained, is discharged into a pipe which returns it to the 1½-inch

Temperature of gas and gravity of condensate from each of the seven stills.

	Temperature of gas in each still, °F.	Gravity of condensate, °B.
Stills 1 and 2.....	150	62
Still 3.....	75	65
Still 4.....	50	73
Still 5.....	40	78
Still 6.....	30	85
Still 7.....	10	95

COOLING SURFACE.

In each still the 1,260 feet of 1½-inch pipe exposes a radiating surface of 412 square feet to the wet gas being refrigerated in the 12-inch tube, or 2,884 square feet in the entire set of seven stills. Of the 2,884 square feet of surface area, 1,648 feet are cooled by ammonia in stills 4, 5, 6, and 7, and 1,236 feet by cold, dry gas in stills 1, 2, and 3 that has passed through the entire set of refrigerating tubes, giving a total of 8.24 square feet of cooling surface for each 1,000 cubic feet of gas treated per day.

COLLECTING CONDENSATE.

The condensate from each still is drawn off continually from the bottom at the low end through a 1-inch pipe manifold to a cone-bottom settling tank in which the gasoline and the water separate by gravity, the water being drawn off at the bottom and the condensate flowing to the storage tanks. The 1-inch manifold and the bottom of each still are connected by a ½-inch gage glass through which the condensate precipitated in that still flows, allowing the operator to see at all times the flow of condensate before it is mixed with that of other stills. By this arrangement he can note, without stopping the plant, whether any discolored condensate is being discharged, or whether any one of the stills is not working properly.

AMMONIA CIRCUIT.

The ammonia used in refrigeration is compressed in the duplex compression cylinders of a 30-ton Stevens ice machine, direct-connected to a 125-horsepower, tandem-compound, steam-driven Corliss engine, with 10 by 20 by 12 inch cylinders taking steam at 110 pounds and operating at 80 revolutions per minute.

From the compression cylinders the ammonia gas is discharged at a pressure of 150 pounds to the inside 1½-inch pipe of a double-pipe water-cooled coil, the water circulating through the outside 2-inch pipe. This coil unit consists of three sets of double-pipe return-bend coils eight pipes high and 20 feet long. Water circulated by a centrifugal pump flows from the coils over a cooling tower, collects in the tower basin and is returned to the coils by the pump at a temperature somewhat below that of the atmosphere. From the inside coils the ammonia flows through a ½-inch pipe to a receiver or storage tank,

made of 8-inch casing 15 feet long, thence through an expansion valve to the four stills, connected in parallel as described above, at a pressure of 15 pounds and a temperature of 10° F. The ammonia is discharged from the four stills into a pipe manifold leading to the ammonia compressor, to be returned through the circuit. Ammonia lost in the pipes and stills by leaks and breaks is replaced from time to time from a steel bottle of compressed ammonia connected to the ammonia circuit as indicated in figure 11.

DESCRIPTION OF PLANT IN SANTA MARIA FIELD.

Plant 10 uses ammonia as an auxiliary cooling agent in addition to water cooling and expansion cooling. At this plant the gas passes through water-cooled coils after each of the three stages of compression, then through a coil cooled with brine refrigerated by ammonia from an ice-making machine, and then through double-pipe coils cooled by expanding gas.

The gas, after being cooled in the high-pressure (250 pounds) water-cooled coils, is led through a continuous coil of 4-inch pipe 450 feet in length, inclosed in a wooden tank or basin built with double walls and bottoms, 9 inches apart, the space between the walls being packed with sawdust. This coil is cooled with brine. The tank bottom has enough slope to drain the brine toward one end, whence it is pumped for recirculation through the unit. The brine (calcium-chloride solution) is brought in contact with the expanded ammonia by the use of coils in an iron tank, reducing the temperature of the brine to about 32° F. From this cooling tank the brine is circulated by a centrifugal pump to the gas-cooling coils, where it is discharged in such a way as to drip over the coil and collect at the low end of the basin, to be discharged again to the ammonia-cooled brine tank.

The gas discharged from the brine-cooled coils has a temperature of 32° to 34° F. The advantage claimed for this system is that the temperature produced by the brine cooling precipitates all the water vapor in the gas, thus preventing freezing of the double-pipe coils cooled by gas from the expansion engine. This is without doubt an advantage to be desired, but it could probably be obtained in this plant, as in other plants, by a more thorough use of expanded gas in coils of greater length and smaller diameter, or by using the expanded gas in two sets of coils and cooling the high-pressure gas in two stages, the first stage using the expanded gas from the second-stage coils. The first coils being partly warmed, would precipitate only water if the temperature were properly adjusted as is done in other plants described. The ammonia compressor and coils, also the brine circulating pumps, coils, and cooler could be abandoned, and only the extra set of expansion coils put in to replace them.

The brine and ammonia cooling installation is cumbersome, inefficient, and requires more time and care than the result warrants.

TREATMENT OF STILL VAPORS BY COMPRESSION AT A REFINERY IN NEW JERSEY.

VAPORS TREATED.

The gases treated in the compression plant, designated as plant 80 in the tables, at a refinery in New Jersey are those from all cooling coils in which the lighter fractions of crude oil and naphthas from both fire and steam stills are being condensed. Figure 12 shows (at the extreme left) the condenser box and coils from which the uncondensed gases and vapors treated by compression originate. From that point each unit and process is shown diagrammatically to the point at which the condensate and fixed gases are finally separated

COLLECTING VAPORS.

At the discharge pipe of the coils in water boxes a T connection is made, the condensate flowing down into pipes connected with the "tail house" and "look boxes"; the gases and vapors rise through a vertical pipe 6 feet high to the 8 or 10 inch collecting pipe called the gas main. The gas main is also connected with a 2-inch pipe to the condensate line at a point about 2 feet back of the look boxes, and with a 2-inch pipe leading from the top of the look boxes, both of which are used to relieve the pressure and collect vapors that have been carried past the first stage of separation, or have formed in the condensate flow lines. From the top of the gas main the gas is led through 12-inch pipe connections past a butterfly valve, which regulates the vacuum held on the discharge pipes of the condenser coils, to a vertical steel receiving tank 15 feet in diameter and 18 feet high. In this tank the gas is given a preliminary scrubbing with sea water, removing part of the sulphur compounds, some heavy oils which have been carried through the stills, and a small quantity of discolored condensate of approximately 53° B. gravity. The 12-inch pipes leading to the receiver are taken out at the top of the gas main, instead of the bottom, so as to trap back any condensate formed in the main and allow it to flow down the 6-foot risers and back into the lines from the coils to the tail house with the rest of the condensates produced. The vacuum held and regulated by the butterfly valve, previously referred to, on the gas mains and on the discharge of the condenser coils is between 0.25 and 1 inch of mercury (2 to 8 ounces below atmospheric pressure). There is no gage between the butterfly valve and the blower that produces the vacuum, so no record of the pressure between these points is available. However, the writer was informed that a test had been made that showed a vacuum of 22 inches of mercury.

SCRUBBING PROCESS.

From the receiving tank a 12-inch pipe carries the gas to a size 8 positive-pressure Root blower which holds the vacuum on the re-

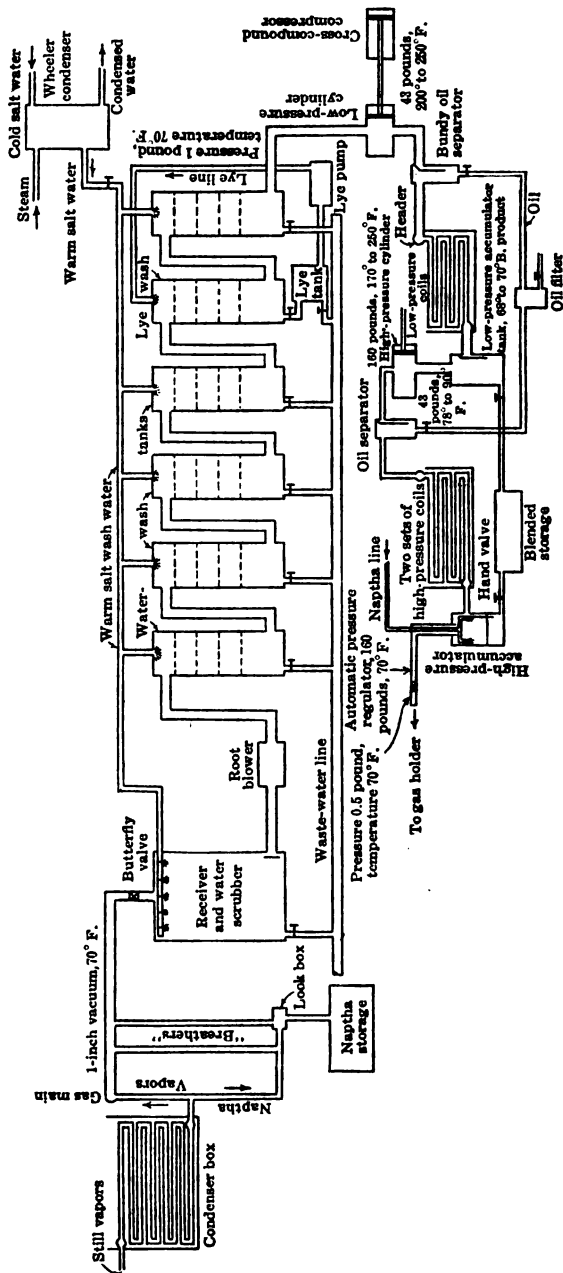


FIGURE 12.—Flow sheet of compression plant at a refinery in New Jersey.

ceiving tank and the gas mains and delivers the gas at a pressure of one pound to the scrubbers and the low-pressure compressor beyond

the scrubbers. From the blower the gas passes through six 4 by 20 foot vertical iron scrubbers connected in series. The connections are so made that by opening or closing valves, the scrubbers may be operated as two sets, in parallel, or three tanks connected in series. This arrangement was tried and abandoned in favor of the series of six. In each scrubber the gas enters at a point about two feet above the bottom, passes a series of wood baffles over which warm wash water or caustic solution is falling, and discharges at the top. The gas then passes through the next scrubber in the series.

In the first four scrubbers warm sea water, flowing over baffles countercurrent to the gas, is used to remove impurities, consisting chiefly of sulphur and sulphur compounds, from the gas. In the fifth scrubber a solution of sodium hydroxide (lye) with a specific gravity of 12° B. is circulated over the wood baffles, in the same manner as the water in the other tanks, to remove any acids contained in the gas. These impurities may originate either in the crude oil or in the refining of the various distillates from which vapors are taken for treatment by compression. The lye used, as received at the refinery from the manufacturer, is a 35° to 40° solution. It is transferred to one of four iron storage tanks and diluted to the strength used in the scrubber. After being circulated until it will not neutralize the acid in the gases and becomes foul, it is wasted and fresh solution is put into circulation.

In the sixth scrubber warm salt water is used to remove any traces of caustic remaining in the gas. Caustic in the gas would react with the lubricating oils in the compressor cylinders, causing cutting of the cylinders or an excessive waste of oil.

The gas in passing through the six scrubbers is warmed 2° to 5° F. by the warm water used as the scrubbing medium. This warm salt water is the discharge from the Wheeler condenser used in connection with the low-pressure steam cylinder of the compressor. The fact that the water used is salt has nothing to do with the process. Sea water is used because it is the most available, the plant being situated on the Atlantic coast. No condensate is formed during the scrubbing. This would be anticipated because of the increased temperature of the gas due to the use of the warm condenser water. Both the water and the lye solution circulated through the scrubber tanks are handled by duplex pumps.

COMPRESSION AND COOLING.

From the sixth scrubber the gas is delivered at a pressure of 1 pound and a temperature of 70° F. to the low-pressure cylinder of the compressor, which discharges it at a pressure of 43 pounds and a temperature varying between 200° and 250° F.

Gas discharged from the low-pressure cylinder to the intermediate cooling coils is passed through a Bundy oil separator, which remove

lubricating oils carried over with hot gas and gasoline vapor from the compressor cylinder. The coils used are the water-cooled type submerged in a box, typical of refinery construction. The gas is divided in a header into six sets of return-bend coils of 3-inch pipe 10 feet long and six pipes high, totaling 360 feet of 3-inch pipe, exposing a radiating surface of 283 square feet, or 0.189 square foot per 1,000 cubic feet of gas treated per day. This is approximately one-third of the radiating area usually found in compression plants for the same service.

At the bottom of the coil the gas is again collected through a header and discharged into an accumulator tank in which 750 to 1,000 gallons of condensate is collected each day. The condensate varies in gravity according to weather conditions, averaging 68° B. in summer and 72° B. in winter. The product collected in this accumulator tank is forced into storage tanks by the working gas pressure as often as necessary and blended with the rest of the condensate. The gas leaving the coils has a temperature of 70° to 90° F., the high temperature probably being due to the small cooling area used at this plant.

At this temperature and pressure (70° to 90° F. and 43 pounds) the gas enters the high-pressure cylinder and is discharged at a pressure of 160 pounds and a temperature between 170° and 250° F. The gas is again led through a Bundy trap to separate lubricating oils, as previously described, and then to the high-pressure cooling coils, which are the same size and length as the intermediate coils used to cool the low-pressure gas, except that two sets are used in series in place of one, having twice the cooling area. The average temperature to which the gas is reduced in these coils is 70° F. and is the lowest temperature used in the treatment.

After the condensate and gas have been separated in the high-pressure accumulator tank the pressure is reduced through a valve to one-half pound and the gas discharged to a gas receiver in which gas is stored and used for fuel under boilers, stills, etc., in the plant.

BLENDING.

Blending at this plant is all done under a pressure of 160 pounds in the high-pressure accumulator tank, as follows:

Naphtha with a gravity of 53° B. is pumped through 1½-inch pipe in coil boxes and cooled to 70° F., then into the top of the high-pressure accumulator tank, and sprayed through the rising gas at a rate which gives a mixture containing approximately four parts of naphtha to one of condensate, or about 80 per cent naphtha. At regular intervals the mixture is drawn off into another tank containing the low-stage condensate, and the resulting mixture sampled and tested for gravity. If the gravity is found to be too high, more

naphtha is pumped into the accumulator tank, which lowers the gravity of the next batch drawn off into the storage tank and of all the blend in storage, or if the gravity was too low the proportion of naphtha pumped into the accumulator is cut down. From 4,000 to 5,000 gallons of raw condensate is made daily in the high-pressure coils, and this with the condensate from the low-pressure coils makes a total production of 5,000 to 6,000 gallons per day from treated gases and vapors. The raw condensate from the high-pressure coils has a gravity varying between 76° and 93° B. After blending with naphtha, the product has a gravity of 58° to 61° B.

The level of the mixture in the high-pressure accumulator tank is at all times kept above the discharge pipe from the coils, thus forcing all the gas to pass through the blended product. It is claimed that this method adds 250 to 500 gallons daily to the net production. Inasmuch as the blend is four parts naphtha to one of condensate, and the temperature of the gas in the coils is such as to leave part of the comparatively heavy gasoline fractions uncondensed, absorption of liquids from the gases or absorption of the gases themselves may reasonably take place. The general practice throughout the United States, however, is to remove the condensate from contact with the gas as soon as possible.

QUANTITY OF GAS TREATED, AND PRODUCTION.

The volume of gas treated is computed from the compressor displacement, and the record of engine revolutions with 5 per cent deducted for slippage. On this basis the gas passing through the plant varies between 1½ and 2 million cubic feet per day, and shows an average production of 3.09 gallons of condensate per 1,000 cubic feet of gas treated.

COMPRESSOR.

All gas compressed passes through a 2-stage Corliss-valve compressor, direct connected to a combination cross-compound, condensing Corliss engine; steam cylinders are 16 and 32 inches in diameter with 30-inch stroke. The compressor speed varies greatly, being dependent upon the amount of gas coming from the stills, which in turn depends upon the stage of distillation of oil at which the various stills are working.

SPECIAL FEATURES OF PLANT.

The noteworthy features of this compression plant are the scrubbers for removing sulphur and acid, the Root blower as a booster unit, the passing of gas through the condensate to bring about greater production of gasoline condensate by absorption, and the large amount of naphtha used in the blended product.

MACHINES USED IN COMPRESSION PLANTS.

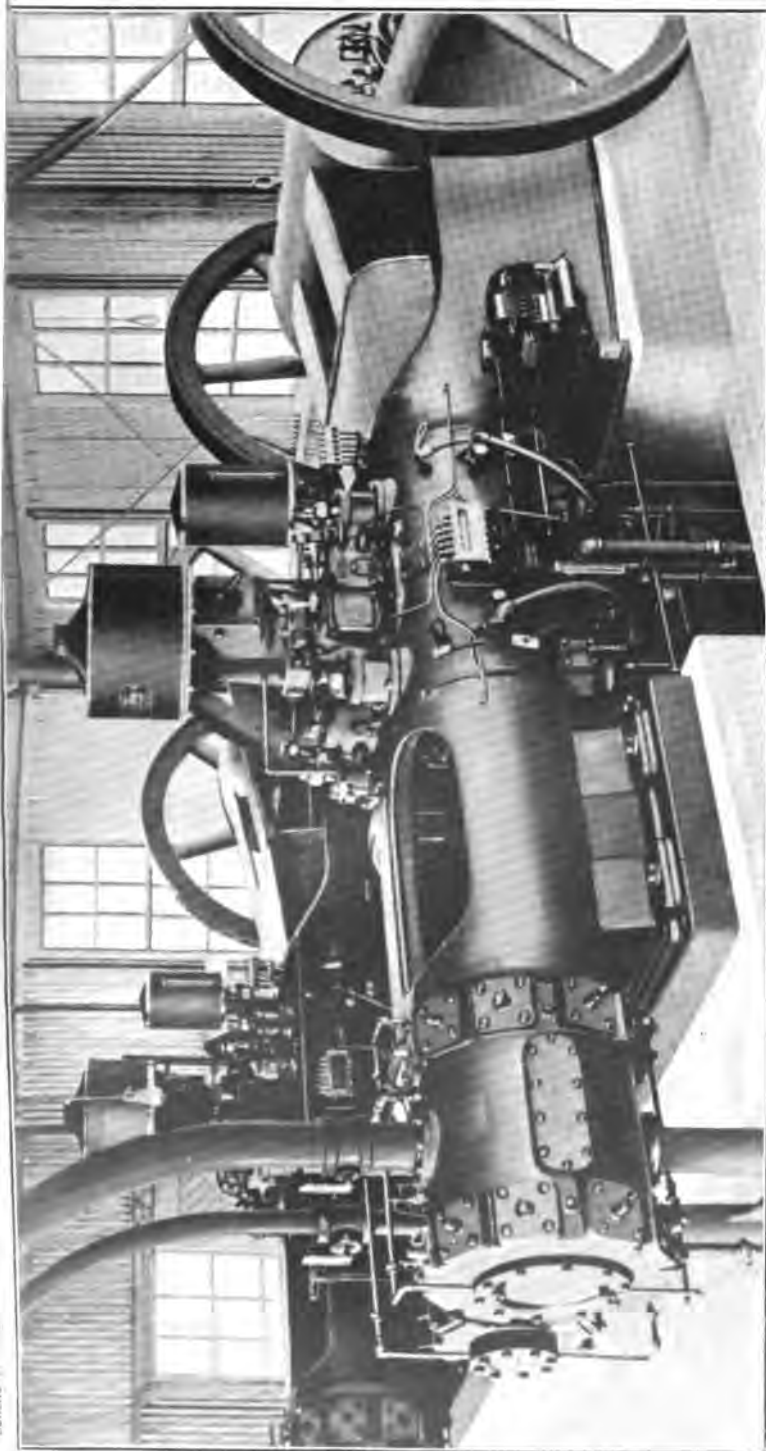
Table 7 shows the total rated horsepower used in gas compression in each of the plants listed, and the number of cubic feet of gas compressed per day by one rated horsepower.

TABLE 7.—*Rated horsepower and capacity of various plants.*

Plant No.	Total rated horsepower.	Cubic feet of gas compressed daily per horsepower.	Plant No.	Total rated horsepower.	Cubic feet of gas compressed daily per horsepower.
3	110	4,100	34	300	2,500
4	300	4,000	35	100	3,500
7	1,800	4,180	36	480	2,400
9	320	3,200	37	170	2,300
11	480	3,100	38	300	2,500
12	240	2,917	50	320	3,700
14	330	3,030	51	110	2,170
16	100	2,500	52	100	2,500
17	300	2,500	54	900	2,500
19	575	3,080	55	300	4,170
20	495	3,030	56	210	1,800
21	300	3,300	57	350	2,400
22	180	3,300	76	300	6,750
30	210	3,500	77	50	8,000
32	695	4,300	78	50	900
33	560	3,200	79	105	2,380

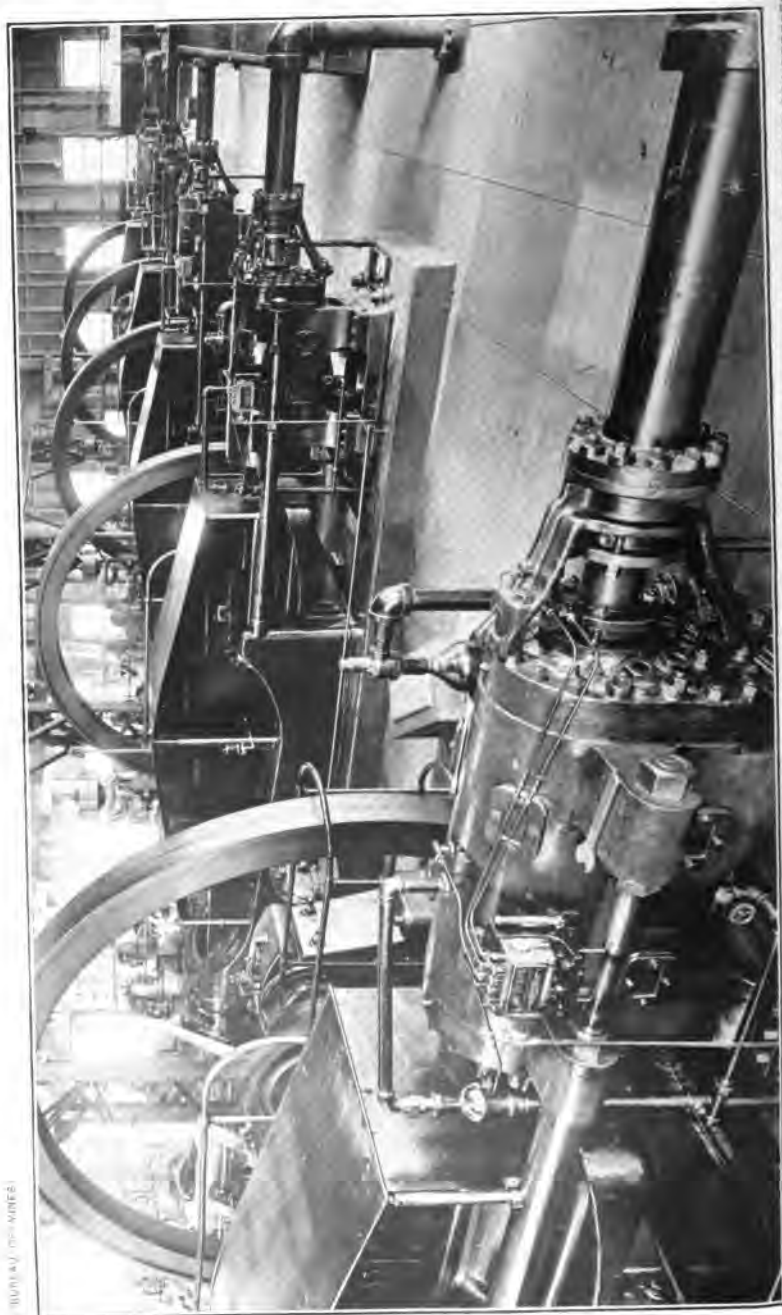
The quantity of gas compressed or treated per horsepower in the plants visited varies between wide limits. The chief causes for this variation are that the intake pressures vary widely and also the final pressures vary between 75 and 300 pounds. Many other factors in plant operation also affect the results, among which are the actual efficiency of the engine and compressor used, the temperature of the gas at different stages, the sizes and length of pipes through which the gas is forced, and the power used in driving pumps and line shafts, which in many plants is taken from the engine that drives the compressor. In plants where expansion engines are used to compress gas no attempt has been made to estimate or add the power delivered by such units.

The table shows that the average plant visited by the writer has 340 horsepower and treats approximately 3,250 cubic feet of gas per day for each rated horsepower installed. The conditions under which many of these plants are operating may be found in Tables 3, 4, and 5. Among operators who design plants and use the rated horsepower, rated compressor capacity, and atmospheric pressure at the intake, with a discharge pressure of 250 pounds, 4,000 cubic feet of gas daily per horsepower is used for preliminary estimates of the requirements of a plant to treat a given volume of gas. The final estimates necessarily must include all the items mentioned above, and also take into consideration all of the special conditions under which the plant in question is to operate.



TWO-STAGE DIRECT-CONNECTED COMPRESSOR AND GAS ENGINE.

(BENTLEY'S MINE)



FIVE 465 BRAKE-HORSEPOWER GAS ENGINES, FRONT-CONNECTED TO 15½-INCH COMPRESSOR CYLINDERS, AT A WEST VIRGINIA PLANT THAT COMPRESSES NATURAL GAS TO A PRESSURE OF 175 POUNDS. MADE DISCHARGE IS FIELD END OF A 30-INCH PIPE LINE.

ENGINES AND POWER.

Machines of practically all well-known manufacturers making gas engines or compressors have found their way into compression plants. One company which has done much pioneer work in both the laboratory and the field, tending to develop the natural-gas gasoline industry, has placed its engines, compressors, or both, in many plants in every field visited by the writer.

Plates XIII and XIV show engine installations at two compression plants.

Table 8 gives data on the motive power, types, and sizes of engines and compressors, method of connection, and the number of compressor units used in the plants visited.

In plant 24, electric motors have been installed to drive the compressors. Originally gas engines were used, but the gas being treated became so rich in gasoline content that not enough gas was discharged after treatment to operate the engines. The motors are set on the blocks that were used for engine beds and are in the same room with the compressors. Because of the possibility that gas may escape about the compressors and be ignited by sparks from the motors, this arrangement would appear to be dangerous practice, but thus far, owing probably to especial precautions in ventilation, no fires or explosions have occurred.

Plants 19, 20, and 21, all built in 1916, use vertical 4-cylinder, 4-cycle gas engines belted to the compressor units. While this type of machine has many moving parts which may get out of order, and a long crank shaft with its bearing to watch and tighten, it is giving complete satisfaction and is claimed to economize fuel and give an overload capacity of 25 per cent.

The 450-horsepower, direct-connected, 4-cycle, double-acting machines, although recognized as standard installations in gas-pumping plants throughout the country, have a number of disadvantages as units for the treatment of gas for gasoline extraction. A machine of this size should be installed only in plants that draw gas from areas large enough to insure a supply for a long term of years, and are of such capacity that one of these large units represents only a small fraction (10 to 20 per cent) of the total plant capacity, otherwise shutting down one unit unbalances the entire plant and materially reduces the output.

TABLE 8.—Data on engines and compressors

Plant No.	Engine.				
	Driven by—	Rated horsepower.	Type. ^a	Number of compressors used. ^b	Drive.
1.....	Steam.....	.....	Cross compound.....	2.....	Direct.....
2.....	do.....	40	Straight line.....	2.....	do.....
3.....	Gas.....	110	Straight-line, tandem, 2-cycle	1.....	Belted.....
4.....	do.....	150	Twin cylinder.....	2.....	do.....
5.....	Steam.....	.....	Cross compound condensing.	1.....	Direct.....
6.....	do.....	.....	Tandem compound condensing.	1.....	do.....
7.....	do.....	.....	do.....	1.....	do.....
8.....	High-pressure gas. ^c	.....	Cross compound, 12 by 25 by 30.	1.....	do.....
9.....	Gas.....	450	Tandem, 4-cycle, double-acting.	2 low.....	do.....
10.....	do.....	450	do.....	2 high.....	do.....
11.....	High-pressure gas. ^c	.....	Cross compound.....	1.....	do.....
12.....	Gas.....	80	Type VII, 16 by 20.....	2 high and 2 low.....	do.....
13.....	High-pressure gas. ^c	.....	Cross compound, 12 by 18 by 10.	1.....	do.....
14.....	Steam.....	.....	Cross compound, 12 by 20 by 12.	2.....	do.....
15.....	do.....	.....	Simple, 12 by 12.....	1.....	do.....
16.....	High-pressure gas. ^c	80	do.....	1.....	do.....
17.....	Gas.....	50	Type VII, 16 by 20.....	6, 3 high and 3 low.....	do.....
18.....	High-pressure gas. ^c	50	Simple, 12 by 12.....	1.....	do.....
19.....	Gas.....	80	Type VII, 16 by 20.....	4, 2 high and 2 low.....	do.....
20.....	High-pressure gas. ^c	.....	Drilling engine, 9 by 12.....	1.....	Belted to pump.....
21.....	Gas.....	110	Twin.....	3.....	Belted.....
22.....	High-pressure gas. ^c	.....	Simple, 10 by 12.....	1.....	Direct.....
23.....	Gas.....	50	Type VII, 13½ by 18.....	2, 1 high and 1 low.....	do.....
24.....	High-pressure gas. ^c	.....	Simple, 10 by 12.....	.....	do.....
25.....	Gas.....	150	Twin cylinder.....	2.....	Belted.....
26.....	High-pressure gas. ^c	.....	Simple, 12 by 11.....	1.....	Direct.....
27.....	Gas.....	175	Vertical, 4-cylinder, 4-cycle..	3.....	Belted.....
28.....	High-pressure gas. ^c	.....	Duplex pump, 10 by 12 by 6.....	2.....	.....
29.....	Gas.....	165	Vertical, 4-cylinder, 4-cycle..	4.....	do.....
30.....	do.....	150	do.....	4.....	do.....
31.....	do.....	Two 40	Type VII.....	4, 2 high and 2 low.....	Direct.....
32.....	do.....	Two 50	Single cylinder.....	1.....	Belted.....
33.....	Electricity.....	35	Motor.....	2.....	do.....
34.....	Gas.....	50	Type VII.....	2.....	Direct.....
35.....	do.....	85-100	Horizontal.....	2.....	Belted.....
36.....	do.....	100	do.....	1.....	do.....
37.....	do.....	50	Single cylinder.....	1.....	do.....
38.....	do.....	70	do.....	3.....	do.....
39.....	do.....	110	Twin.....	2.....	do.....
40.....	do.....	165	do.....	9, 4 running.....	do.....
41.....	High-pressure gas. ^c	.....	Cross compound, 12 by 19 by 18.	1.....	Direct.....
42.....	Gas.....	Eight 50	Type VII.....	10, 5 high and 5 low.....	do.....
43.....	High-pressure gas. ^c	Two 80	Cross compound, 8½ by 12 by 12.	1.....	do.....
44.....	Gas.....	50	Type VII, 13½ by 18.....	6, 3 high and 3 low.....	do.....
45.....	do.....	70	Single cylinder.....	1.....	Belted.....
46.....	do.....	50	Type VII, 13½ by 18.....	2, 1 high and 1 low.....	Direct.....
47.....	do.....	50	Single-cylinder, 13½ by 18.....	6, 3 high and 3 low.....	do.....
48.....	do.....	80	Type VIII, 16 by 20.....	do.....	do.....
49.....	do.....	110	Twin-cylinder.....	1.....	Belted.....
50.....	do.....	50	Type VII, 13½ by 18.....	2, 1 high and 1 low.....	Direct.....

^a Figures show size of cylinder in inches.^b In this column "low" refers to low pressure, "high" to high pressure.

sed at various compression plants.

Compressor.			Rated speed (r. p. m.).	Remarks.
Description.	Size of cylinder (inches).			
	Low-pressure cylinder.	High-pressure cylinder.		
2-stage.....	21 by 24.....	9½ by 24.....	62	Two 300-hp. Sterling and four 150-hp. Erie boilers used.
Single-stage.....	12 by 16.....		200	
2-stage.....	13½ by 14.....	6½ by 14.....	160	
...do.....	16 by 16.....	8 by 16.....	180	
2-stage.....	20 by 24.....	9½ by 24.....	125	
...do.....	15 by 24.....	7 by 24.....	145	
...do.....	15 by 16.....	7½ by 16.....	115	
...do.....	24 by 30.....	12 by 30.....	38	
Single-stage.....	31 by 36.....		125	
...do.....		15½ by 36.....	125	
Single-stage (duplex).	Two 22 by 16..			
Single-stage.....	14 by 20.....	7½ by 20.....	200	
2-stage.....	16 by 10.....	8 by 10.....	100	
...do.....	20 by 12.....	12 by 12.....		Used as low and intermediate at 12 pounds and 80 pounds.
Single-stage.....		8 by 12.....	Varied.		Used as high at 250 pounds.
...do.....	14 by 12.....			Used as air compressor.
...do.....	Three 14 by 20.	7½ by 20.....	180	
...do.....	14 by 12.....		145	Pumps dry gas at 60 pounds.
...do.....	Two 7 by 20...	Two 14 by 20...	190	
2-stage.....	13 by 14.....	6½ by 14.....	170	
2-stage, tandem.....	8 by 12.....	4 by 12.....	200	
Single-stage.....	11 by 18.....	5½ by 18.....	180	
...do.....	12 by 12.....			
2-stage.....	16 by 16.....	8 by 16.....	150	
Single-stage.....	20 by 11.....		78	
2-stage.....	16 by 16.....	8 by 16.....	158	Engine speed, 300 revolutions per minute.
...do.....				Water discharge throttled to 100 pounds.
...do.....	16 by 16.....	8 by 16.....		Drilling engine, 10 by 12-inch cylinder, used as expansion engine.
...do.....	16 by 16.....	8 by 16.....	150	Engine speed, 275 revolutions per minute.
Single-stage.....				Drilling engine, 10½ by 12-inch cylinders, used as expansion engine.
2-stage.....	11 by 15.....	7 by 15.....	115	
...do.....	14 by 10.....	7½ by 10.....	120	
Single-stage (to 150 pounds).			180	
2-stage.....	12½ by 14.....	6 by 14.....	180	
...do.....	12½ by 14.....	6 by 14.....	180	
...do.....	10½ by 12.....	5½ by 12.....	180	
...do.....			180	
...do.....	14 by 14.....	7 by 14.....	180	
...do.....	16 by 16.....	8 by 16.....	180	
Single-stage (duplex).	18 by 18.....			Feather valves on compressor.
Single stage.....	Eight 12 by 18.	Eight 6½ by 18.	200	
Single-stage (duplex).	Two 14 by 20.	Two 7 by 20...		
...do.....	14 by 12.....			
...do.....	12 by 18.....	9 by 18.....	100	
2-stage.....	12 by 12.....	6 by 12.....	180	
Single-stage.....	10 by 18.....	5½ by 18.....	180	
...do.....	12 by 18.....	6 by 18.....	180	
...do.....	14 by 20.....	7 by 20.....	180	
2-stage.....	13 by 14.....	6 by 14.....	160	
Single-stage.....	12 by 18.....	6 by 18.....	180	

c Expansion engine operated by expanding high-pressure, treated gas through it.

TABLE 8.—Data on engines and compressors.

Plant No.	Engine.				
	Driven by—	Rated horse-power.	Type.	Number of compressors used.	Drive.
53.....	{ Gas.....	{ ^a 80	Type VII.....	2, 1 high and 1 low....	Direct.....
	{ ..do.....	{ ^b 50	Type VIII.....	do.....	do.....
	{ ..do.....	{ 80	Twin.....	1.....	Belted.....
	{ ..do.....	{ 150	2-cylinder, tandem.....	1.....	do.....
54.....	{ ..do.....	{ 50	Type VII.....	6, 3 high and 3 low....	Direct.....
	{ ..do.....	{ 150	Twin-cylinder.....	2.....	Belted.....
	{ ..do.....	{ 150	do.....	2.....	do.....
55.....	do.....	50	Type VIII.....	6, 3 high and 3 low....	Direct.....
56.....	do.....	70	Single-cylinder.....	3.....	Belted.....
57.....	do.....	70	do.....	5.....	do.....
58.....	do.....	50	Type VIII.....	.....	Direct.....
59.....	do.....	50	do.....	.....	do.....
60.....	do.....	50	do.....	.....	Belted.....
61.....	do.....	.....	.....	.....	do.....
62.....	do.....	50	Type VIII.....	.....	Direct.....
76.....	{ ..do.....	{ 50	Type VIII, 13½ by 18.....	4.....	do.....
	{ High-pres- sure gas. ^c	{ ..do.....	Duplex, 13½ by 18.....	1.....	do.....
77.....	{ Gas.....	{ 50	Type VIII.....	.....	do.....
	{ High-pres- sure gas. ^c	{ ..do.....	.....	.....	.....
78.....	{ Gas.....	{ 50	do.....	1.....	Direct.....
	{ ..do.....	{ ..do.....	Pump, 10 by 6 by 12.....	2.....	.....
79.....	do.....	35	Single cylinder.....	2.....	Belted.....
80.....	Steam.....	.....	Cross compound, Corliss, 18 by 32 by 30.	1.....	Direct.....

^a Low pressure.^b High pressure.

used at various compression plants—Continued.

Compressor.			Rated speed (r. p. m.).	Remarks.
Description.	Size of cylinder (inches).			
	Low-pressure cylinder.	High-pressure cylinder.		
Single-stage				
do				
2-stage	15½ by 16.....	7½ by 16.....		
do	14 by 14.....	6½ by 14.....		
Single-stage	11 by 18.....	6 by 18.....	180	
2-stage	16 by 16.....	7 by 16.....	180	
do	16 by 16.....	7 by 16.....	180	
Single-stage	11 by 18.....	5½ by 18.....	180	
2-stage	12 by 12.....	6 by 12.....	180	
do	12 by 12.....	6 by 12.....	180	
.....				
.....				
Single-stage	11½ by 18.....			
2-stage				Compresses air in two stages to 85 pounds.
Single-stage	11½ by 18.....			
do				
.....	11½ by 18.....			
2-stage	12 by 12.....	6 by 12.....		Feather valves on compressor.
do	25 by 30.....	13 by 30.....		Corliss valves on compressor.

c Expansion engine operated by expanding high-pressure, treated gas through it.

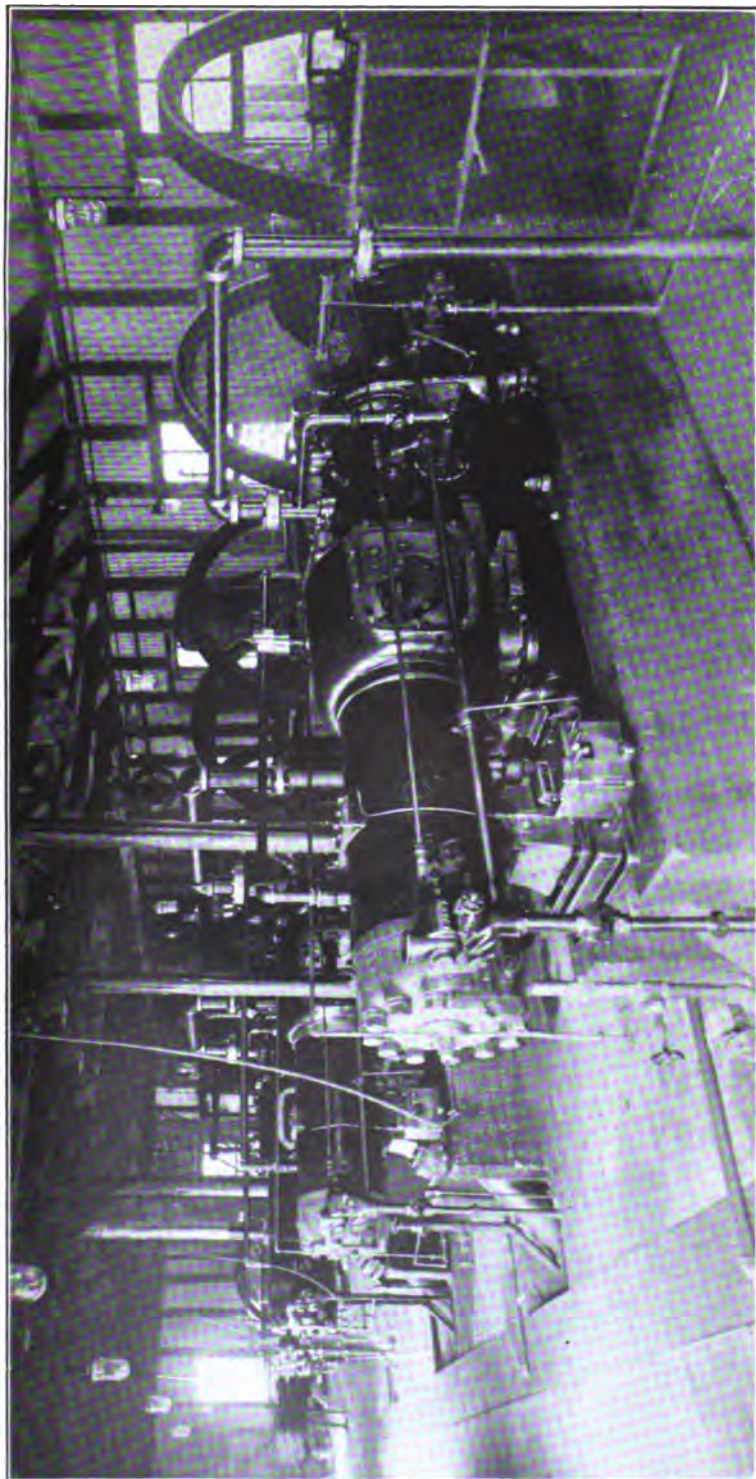
In the casing-head gasoline industry the gas supply from a given area is expected to decline and the pressure necessary to precipitate the condensable product usually becomes lower as the gas becomes richer. If all the power capacity thus relieved from duty is not used to increase the vacuums held on the lines, it is obvious that to remove one unit to another locality would be desirable. If one unit represented half the total plant capacity, it would be necessary to wait until the available supply of gas had been reduced 50 per cent before that unit could be transferred, but if that unit represented only 20 per cent of the plant capacity it could be removed when the gas had fallen off that amount; also it would be a much simpler matter to find a location or sale for a machine of one-half million feet capacity than for a machine requiring from three to four million feet per day. Another argument for machines of smaller capacity is the size and weight of parts which under the usual transportation conditions in oil fields is a serious problem in plant construction.

Both direct-connected (Pl. XV) and belted units are being installed in compression plants using the usual smaller units. However, many operators of wide experience prefer the belted drive, claiming that it simplifies repairs and renewals and gives a wider choice both of engine and compressor. The belted type requires larger buildings, because of the necessary distance between pulley centers, which the writer found to vary between 22 feet for vertical engines to 34 feet for horizontal types. In some plants two buildings are used, one containing the engines and the other the compressors, with belt galleries connecting the two. This is done as a precaution against fire and explosions.

TYPES OF MACHINES USED AS EXPANSION UNITS.

All expansion engines used in compression plants are machines originally designed to use steam that have been slightly modified to overcome the effects of the low temperatures from the use of compressed gas in the steam or power cylinders. Among the machines found in use are direct driven reciprocating pumps, drilling engines, and simple and cross compound compressors. Of these the reciprocating pump is the least to be recommended. The valves tend to freeze and stick, owing to the general design and slow action, and its efficiency as a power unit and its capacity are low.

Of the machines used as expansion engines the converted steam engine of the single or double stage (simple or compound) type is more often found than any other make. On these engines, remodeled for the expansion of high-pressure gas, the valve mechanism has been designed especially and made stronger for this particular service. The exceedingly low temperatures developed in the cylinders tend to freeze the valves, causing excessive strains on the valve stems and rods, and also make lubrication difficult.



DIRECT-CONNECTED COMPRESSOR AND GAS ENGINES.

Glycerin has universally been found to be the best lubricant for expansion cylinders and was in general use until the recent rise in price, and the difficulty of obtaining a reliable supply forced plant operators to try other oils, some of which have been found usable but not as satisfactory as glycerin. As the supply of that lubricant increases it will indoubtably again be generally used.

Other types of steam compressors and, in several plants, drilling engines belted to plunger or centrifugal pumps, are in use as expansion units, and, according to the operators using them, are giving satisfaction in regard to both capacity and temperatures. The loads of the drilling engines were varied to meet the conditions of pressure and volume of gas by throttling the flow of water from the pump, thus giving the required resistance for the development of power at normal engine speeds. The valve mechanism of the drilling engines was rebuilt and strengthened to meet these conditions.

At one plant where a drilling engine gave much trouble from freezing the piston rings were removed and the piston dressed to a square edge. The piston in this condition shaved the ice from the cylinder walls, thus preventing sticking or freezing. No lubricant was used in the cylinder, the film of ice or frost on its walls acting as a lubricant, and leakage past the piston after the film had formed was very small.

At plant 3 an engine of this type that has a 9 by 12 inch cylinder, making 90 revolutions per minute with one-fourth cut-off, takes gas at 130 pounds, gas at 250 pounds being throttled to that pressure, and exhausts it at 10 pounds. The engine is belted to a three-plunger pump throttled to a back pressure of 160 pounds in order to increase the load on the engine. The water pumped is used in the cooling towers and in the engine and the compressor jackets.

At plant 16 the expansion engine, accumulator tanks, and storage tanks are all housed in a double-wall insulated building. The advantage claimed is that the condensate is held at a low temperature in the storage and other tanks, thus preventing loss by evaporation through heating before blending. The condensate precipitated in the coils is kept from sudden and extreme rises in temperature, as would be the case if the storage tanks were not cooled or shaded. The temperature in the building and of the condensate in storage is thus held between 34° and 50° F.

Expanding the compressed, treated gas in engines to develop power for driving compressors or pumps is not an economy, because of the small amount of actual power delivered, the care necessary, and the cost of upkeep and lubrication, such engines being used only because the cooling effect the expanded gas has in the treatment of high-pressure gas in double-pipe coils or heat interchangers.

In simple expansion engines such as pumps, drilling engines, or single-expansion compressors the compressed gas before entering the

power cylinder is often reduced by a throttle valve from the maximum pressure used in the plant to pressures varying between 120 and 160 pounds, depending upon the design and size of the machine and the pressures for which it was built and under which it gives the best results.

Cross-compound machines usually take the gas at the maximum plant pressure and reduce the pressure in the first expansion to 30 to 60 pounds (see Table 5) and in the second stage to between 5 and 15 pounds. Generally the gas goes from the first-stage expansion cylinder to a drip or small accumulator tank, then directly to the low-stage cylinder. In plant 6 (see Table 4, p. 41), the gas from the first-stage expansion is led through a set of double-pipe coils and heated before being put through the second stage of expansion. By this system both the power developed in the expansion engine and the cooling efficiency of the expanded gas are increased, also the danger of freezing in the expansion cylinders is less.

COMPRESSORS.

Direct-connected compressor units are usually of the single-cylinder engine, single-stage type, although some plants in the eastern and Mid-Continent fields are using direct-connected, twin 2-stage machines. Of the direct-connected compressors the single-stage unit, found more often than any other make, as shown in Tables 8 and 9, has the engine and compressor cylinders opposed, or on the opposite sides of the fly wheels.

The sizes and types of compressors used in the various plants visited by the writer are shown in Table 8 (p. 74), which conveys an idea of the great variety of compressors and drives used in such plants.

AUXILIARY MACHINES.

In all natural-gas gasoline plants small engines are needed to circulate water in jackets, towers, and ponds, to produce electricity for light and pump air to start gas engines. The number, situation, and type and size of these units are generally matters of preference with each plant operator and no standard has been followed.

WATER-CIRCULATING PUMPS.

Many of the newest plants have centrifugal pumps belted to a pulley on the engine, which circulate the water used in both engine and compressor cylinder jackets; other plants use a line shaft with pulleys belted to the engines and to the centrifugal pumps. In many fields the water is heavily charged with mineral salts, and the water used in the cylinder jackets is often distilled or condensed and kept separate from that used in cooling the gas coils. This is often done by cooling the condensed water in a separate tower or by passing it through coils

in the main gas-cooling tower that are cooled with spray in the same way that the gas coils are cooled. In the latter method the condensed water is pumped from the coils in the tower through the jackets and back to the coils in a closed circuit. Where a separate tower is used the condensed warm water is sprayed in the tower, collected in the basin beneath the tower, and circulated by pumps through the jackets, and returned to the top of the tower to repeat the cooling and aeration. In this method the loss of condensed water in the tower is so great that it is not to be recommended unless the condensed water is easily made or obtainable from a boiler plant. The cooling effect gained is better, and the installation less expensive, if the cost of condensed water is not an object.

For circulating the water used to cool the gas, usually centrifugal or plunger pumps driven by small (5 to 10 horsepower) gas engines, or belted to a line shaft, are installed.

AIR PUMPS.

Air pumps for compressing air in receivers to start the main gas engines are generally single-cylinder pumps or compressors belted to gas engines, previously mentioned, or, in some plants, to a line shaft driven by a small gas engine. The receivers are built to stand pressures up to 250 pounds. When the desired pressure is built up in the receiver, the air pump is shut down until the pressure is relieved by use in starting the main gas engines, or by leakage, when the pump is again operated until the required pressure is obtained.

LIGHTING EQUIPMENT.

The necessity of using strong, reliable inclosed lights around compression machinery and the danger of open flames in plants treating natural gas at high pressures has forced operators to install small electric generators as part of the equipment of gasoline plants.

The electric plant is always housed in a building separate from the compressors, and usually in the building with the air and water pumps. The unit consists of a gas engine belted to a dynamo of a size and capacity suitable to the lighting needs of the plant, and is operated only at night. In large gas-pumping stations storage batteries are used both for light and for engine ignition, in place of direct connections.

GASOLINE PUMPS.

Plants situated some distance from the shipping point or blending station often require pumps to force the gasoline through the pipe lines to such stations.

The product is often blown from one tank to another by turning high-pressure gas into the tank containing the product, but where the

distance is great this method is not always satisfactory, and pumps of either rotary or reciprocating type are installed, usually being operated by belt connections to small gas engines. It is claimed for the rotary pumps that condensate losses are smaller than from the use of other types, because the agitation is less and the flow more steady and quiet through the pump and into the lines.

BLENDING AND SHIPPING THE CONDENSATE.

Although blending of compression-plant condensates is not done primarily for the purpose of making a product that will meet the specifications required by transportation laws governing the shipment of gasoline by rail or water, blending and shipping have become such important functions, one of the other, that a separate discussion of the blending process and the transportation of the blended stock is not desirable.

REASONS FOR BLENDING.

When the condensate produced by compression is allowed to weather unblended until its vapor tension is reduced to less than 10 pounds at 100° F. and its temperature rises to atmospheric, losses ranging up to 75 per cent of the total product often result, whereas if the condensate is mixed (blended) with heavier straight still-run refinery distillates the losses from weathering are reduced, usually to one-half that amount, and often more. This fact has led condensate producers to take advantage of blending to increase the volume of the product actually marketed, thus increasing their profits and also the supply of marketable motor fuels so desirable under present conditions. The development in gasoline motors up to the present time has not reached a stage that would make the heavier still distillates, such as are used for blending, a convenient or economical fuel if used as made, because of the difficulty in starting the motor with such fuel and its tendency to deposit carbon in the cylinders and on the pistons from incomplete combustion, causing "engine trouble."

Condensate produced by compression is also an undesirable fuel for gasoline engines. It is exceedingly volatile, which causes losses in handling, is dangerous because fumes are easily formed, and gives less power as compared with equal volumes of heavier distillates, a larger number of gallons being required to develop the same power. It gives a quick, sharp explosion in a motor cylinder, but seems to lack "push" after the explosion has taken place. In the above qualities it is in no way different from still-run products of similar gravity and similar end points, both products needing additions of less volatile, heavier, and more powerful fractions in order to form the most convenient and economical motor fuel.

The lighter fractions of petroleum distillates, as compared with the heavier products, have a lower calorific value per gallon but a

higher calorific value per pound. As all products of petroleum are sold in the United States by volume or liquid measure, the standards for comparison must be made on the heat units per volume and not per weight.

As previously stated, another important factor in blending is transportation. The Interstate Commerce Commission rules controlling shipments of petroleum products and liquefied natural gas allow transportation of petroleum distillates having vapor tensions of less than 10 pounds per square inch in standard tank cars, and products with vapor tensions of 15 pounds per square inch in specially built insulated tanks. As many plants produce condensate that has a vapor tension of 30 or more pounds as it comes from the accumulator tanks, blending and weathering are both resorted to by most manufacturers in order to bring the product within shipping rules, to increase the quantity, and to improve the quality of the product.

MARKETING UNBLENDED CONDENSATE.

A small quantity of natural-gas gasoline finds its way to consumers unblended. It is sold as "gas-machine gasoline," a product with a gravity of 80° to 86° B., used to make gas for certain domestic, commercial, and chemical purposes, and as "export gasoline," a product with a gravity of 74° to 80° B. and of 4 to 6 pounds vapor tension, which is usually sold in containers to foreign trade.

The great bulk of condensate, however, is blended in one way or another before it reaches the consumer, but not always completely blended at the plant where it is made, or by the producer.

In many eastern fields the condensate is held in storage under pressure until a given quantity is ready for shipment, when it is forced by gas pressure or pumps through small (2-inch) pipe lines to the tanks of firms making a specialty of blending and marketing motor fuels, and having blending stations centrally situated among the compression plants from which they receive condensate. Products having a gravity as high as 84° B. are shipped in this way to blending companies.

SHIPPING BY AUTO TRUCK.

Another method of shipment, used mostly in California and northern Pennsylvania, is by tanks mounted on auto truck. Two plants shipping condensate of 80° to 83° B. gravity in this way are situated 30 miles from the blending stations of the buying companies. These are unusual examples, but a number of plants ship their product 6 to 10 miles in tanks of this character. Generally the tank is kept under a pressure of 10 to 20 pounds in order to reduce losses of the light condensates from agitation and heating during transportation.

TRANSPORTING CONDENSATE IN CRUDE OIL.

Certain large producing and refining companies in California which buy or produce casing-head gasoline gage the product in the storage tanks at the compression plants for settlement, and have the condensate pumped directly into their crude oil storage or pipe lines leading to their refineries. They not only recover the gasoline when the crude oil is refined, but take advantage of the fact that the condensate "cuts" the crude, making it flow through the lines more easily. The extremely light fractions that are thus injected into the crude oil, and will not condense in the usual refinery condenser boxes, can be and are in many refineries compressed and cooled as in compression plants. This product is immediately blended at the refinery and thus held and sold.

As previously mentioned, a company in the Mid-Continent field produces only such condensates as can be shipped in tank cars. This is done by regulating the pressures and the temperatures used in the compression plant, so that only such condensate as can be shipped unblended will be precipitated.

A plant in California and some plants in other fields reduce the unblended condensate to conform with the shipping rules by weathering, because of the cost of shipping in blending naphtha. The condensate is exposed in storage tanks to atmospheric temperature and pressure until the vapor tension is reduced to the desired point, and then shipped in insulated cars. At times warming with steam is resorted to if the atmospheric conditions do not bring about the proper results. The use of steam is not to be recommended, however, except when absolutely necessary, because of the loss of some of the heavier fractions with the lighter ones.

METHODS OF BLENDING.

Blending condensate with the various distillates used for that purpose, as practiced at present, is done at times in stages, and at many different points in the precipitation, storage, or transportation of the product.

The product of plants that ship their condensate without being blended usually goes to refineries or blending stations belonging to purchasers of this type of product, who blend the condensate before sending it to the retail markets. One blending company in West Virginia buys condensate, pumps it to the plant in pipe lines, stores it in closed tanks until needed, then blends it with naphtha in the following manner:

A tank car of naphtha is one-half unloaded, usually into an empty tank car, and then condensate is slowly pumped in through a valve in the bottom until the tank is filled. The condensate rises through

the naphtha and slightly agitates it, and in this way becomes absorbed and blended with the naphtha. At times the operation is reversed, a tank car being half filled with condensate and the naphtha pumped in from above. No further treatment is used, the car being shipped as soon as filled. The agitation during shipment tends to complete blending if such is necessary.

Blending practice at some refineries and casing-head gasoline plants is practically the same as described above except that stationary tanks are used in place of tanks on cars. At other blending plants a pump is used in blending, its suction being connected with two tanks, one of blending stock and the other of condensate. The flow of each is regulated in the pipe line by valves, the discharge of the pump going to a storage tank. From time to time the mixture in the storage tank is tested for gravity, if the blend is too light or too heavy the flow of either naphtha or condensate is adjusted to give the desired mixture.

At some plants methods of blending are more complicated. The procedure used by one company receiving its condensate by auto truck is as follows: A given quantity of California distillate with a gravity of 53° to 55° B. is placed in a cone-bottom blending tank, where it is washed with acid solution, caustic solution, and water; after this treatment condensate with a gravity of 72° to 82° B. is forced into the tank from the bottom. Air is then blown through the mixture to agitate it and remove the lightest fractions of condensate and dissolved gases. The mixture is tested for specific gravity, after which enough still-run California gasoline with a gravity of 58° B. is added to bring the whole to a gravity of 60° B. The blended gasoline produced by the above method and ingredients is sweet, water white, and has the following characteristics: 5.9 per cent distills over up to 140° F., the distillate having a gravity of 79.9° B.; 70 per cent distills over up to 246° F.; and 30 per cent distills over between 246° and 344° F.

Distilling this blended product in 5 per cent cuts shows it to be an exceptionally good motor fuel with none of the usual fractions missing.

While holding condensate in storage some blending companies and refineries, as well as compression-plant operators, keep the tanks containing such stock under pressure and often the tanks are insulated or housed and shaded in order to reduce evaporation by the sun and the atmosphere, one company having gone to the expense of building a louver tower over the tanks and keeping small sprays of water constantly covering them. The tanks, which are held under pressures of 10 to 20 pounds, are set in a concrete or wooden basin. The water collects in this basin, thence it is again circulated over the tanks by pumps. No outside cooling of the water is resorted to, the

evaporation from falling through the tower and over the tanks being sufficient to keep the water at a temperature considerably below that of the atmosphere, also any volatilization of the condensate itself tends to cool the liquid.

Where blending is done by refining or blending companies, as has been described, the operation is complete and the blended product is ready for market. The blended gasoline made in the Eastern fields has a gravity of between 65° and 70° B., and that made in California between 58° and 63° B. The difference in gravity is due to differences in the character of the crude oils from which the condensate and the blending stocks were made; this variation is discussed in later paragraphs. The blending is usually done so as to bring the product to a given gravity by the mixture of the two ingredients, whereas the final end point is determined by, and is the same, as the end point of the naphtha used. Although the proportions vary under these conditions, the proportions to be mixed to make a product of a given gravity can be approximately calculated from the gravity and the end points of the two liquids.

The methods of disposal of condensate mentioned are found mostly in California and some eastern districts; with few exceptions the practice in the Mid-Continent field is to blend either at the compression plant or at the loading station operated in conjunction with the plant.

BLENDING BY PLANT OPERATORS.

When the blending is done by the operator of the compression plant, one of the following methods is generally adopted: (1) Blending all of the condensate at the blending station or loading racks; (2) blending to a given stage at the plant, and transferring the partly blended product to the loading racks and either finishing the blending there or shipping it to some point at which naphtha is cheaper or more readily obtained; and (3) completing the entire operation at the plant.

BLENDING AT THE LOADING RACKS.

Many of the companies controlling two or more compression plants, situated in the same field and tributary to the same shipping point on a railroad, have adopted the method of blending the products from all their plants at a central station. A centrally situated loading station with racks and tanks (see Plate XII, A, p. 52), is necessary in any event for storing and loading the plant products and unloading and storing the blending stocks, so that the stations can be also fitted for blending practically without additional cost of labor and small increases in tankage.

In stations used in this way, the usual equipment consists of tanks of any desired capacity for the storage of naphtha, other tanks for

the storage of condensate, and tanks for the blended stock and from which the marketable product is transferred to tank cars for shipment.

The plant condensate is pumped or forced by its own pressure through small pipe lines into the condensate storage tanks, and the naphtha from tank cars is pumped into the naphtha tanks. From the naphtha storage tank a given quantity of naphtha is first pumped into the blending tank, then condensate is forced into the blending tank at the bottom, being allowed to rise through and be thoroughly absorbed by the heavier naphtha. When the predetermined quantity of each stock has been mixed in the blending tank, samples are tested for gravity, and if any change in gravity is desired more of the heavy or light stock is added, as the tests indicate to be necessary. The blended gasoline is next tested for vapor tension, and, if it is found to be too high for shipment in the cars used (standard or insulated tanks), the tank is allowed to stand open to the atmosphere for several hours, or even days, if necessary. In some plants it has been found necessary to heat the blended products to 80° to 90° F. with steam, in order to reduce the vapor tension to the required point in a limited time, so that the blending could continue without the installation of an excessive amount of tankage. Heating with steam should not be resorted to if avoidable, as a quick rise in temperature drives the lighter condensates off rapidly, carrying with them portions of the heavier and less volatile fractions. When the specific gravity and the vapor tension have been brought to a point within the regulations governing shipments of gasoline, the contents of the blending tank are either drawn off into cars for immediate shipment or pumped into a storage tank.

The blending method used at the majority of such stations usually consists merely of mixing calculated quantities of the different stocks to be disposed of and reducing the vapor tension of the mixture by open contact with the air or by slight warming with steam coils, placed in the blending tank.

The advantages of blending at loading and storage stations are that the productions of a number of plants can be handled, close connection with railroad service, and the low cost of handling both the naphtha and the blended stock. At times the tank cars are used as blending tanks, as described in a previous paragraph.

PARTIAL BLENDING AT PLANT.

Some operators, because of the plant being in a place where it is difficult or costs too much to bring in large quantities of naphtha, or, more often, because the company controls a refinery and desires to refine the gasoline by further treatment, such as distilling, have adopted the practice of blending only so far as is necessary for shipment at the compression plant or blending station, the final blending

and treatment being given at the refineries or points where the desired quantities and qualities of distillates may more readily be obtained. Some operators blend partly at the plants and finish the operation at the blending station or loading racks as described above, thus saving the costs of handling, of pipe line, and of the pumping capacity necessary to transfer all of the heavy blending stock to the plant and back to the loading station.

When the blending is completed at the blending station, it is done in the way described, except that smaller proportions of heavy naphtha are added, because some heavy naphtha has been previously added to the condensate at the plant.

PLANT BLENDING METHODS.

Plants at which blending is entirely or partly completed have developed methods and practices quite different from the usual way of mixing the two constituents in a blending tank. Many plants still blend the condensate and the naphtha in storage or blending tanks, using the methods previously described above, but a tendency has developed for blending at much earlier stages of the process.

BLENDING IN "MAKE TANKS."

The first step in this development was when certain operators pumped blending naphtha into the tanks known as "make tanks" (see Pl. IV, C, p. 26, and XII, C, p. 52), which receive the condensate from the accumulator tanks, and in which the total make of one day or shift was measured before being transferred to storage. The method as now used is to pump naphtha into the tank at such a rate that the percentage in the mixture would be somewhat below that desired in the final blend, or to place a given quantity of naphtha in the make tank and discharge condensate from the accumulators into the naphtha. In transferring condensate from the accumulator tank to the make tank, the sudden release of pressure causes violent weathering or boiling, owing to the high vapor tension. By adding heavier blending stocks at this point the vapor tension is lowered, with consequent lessening of losses from the light condensate and dissolved gas weathering rapidly and carrying off with them part of the heavier fractions.

The product of this blend is gaged in the make tank, the quantity of naphtha deducted, and the actual plant production calculated. At the end of each day or shift the mixture is transferred to storage tanks and the blend completed or shipped to another point for blending as described above.

BLENDING IN ACCUMULATOR TANKS.

Blending in accumulator tanks, as found in practice by the writer, consists of pumping naphtha slowly and continually into the tanks, connected with the high-pressure coils, at a pressure a few pounds in

excess of that at which the gas is being treated. The naphtha is injected into the tank through small ($\frac{1}{4}$ -inch) pipes at a point near the top and through fittings which cause a spray, the theory being that the spray will collect fine particles of condensate in falling through the gas and reduce the gravity and the vapor tension of the product before it is released from the high pressure at which it is precipitated and thus reduce losses of condensate.

Operators using this method claim it produces a marked increase in plant production, one in particular claiming a net increase of 10 per cent. The mixture is drained from the accumulator tank as in other practice, either automatically or by hand, as the custom of the plant may be, the quantities being figured as previously described to determine the plant production.

HOT BLENDING.

When naphtha is injected into the high-pressure gas while it is in the coils, or before it has reached the coils, and is still hot from compression, the method is called "hot blending."

This method has been adopted at some plants where the gas treated contains large proportions of the exceedingly light fractions and the condensate had shown extreme losses in storage and during weathering and blending by other methods. A Pennsylvania operator producing condensate with a gravity of 92° to 95° B. claims a net gain of 15 per cent in marketed condensate from the use of this method, and one in Oklahoma, approximately 30 per cent.

Hot blending has been tried out at two California plants, in different fields, to the writer's knowledge and no advantage gained. The plants produce condensate with a gravity of 82° to 86° B., using pressures between 200 and 250 pounds.

One eastern plant, which compressed the gas to 300 pounds pressure, injects naphtha through a needle valve placed in the high-pressure water-cooled coil header at the intake (hot) end of the coil. The naphtha is pumped through the valve at a pressure of 400 pounds per square inch, which causes it to spray or atomize in the header and intimately mix with the hot gas as the gas divides into the coil pipes leading out of the header. The first few (10 to 15) feet of this coil is kept dry to permit the hot gas to vaporize as much of the naphtha as possible before the gas and the naphtha are cooled by the water sprayed over the rest of the coil.

What happens to the injected naphtha is not definitely known, but it appears that the naphtha is divided into three parts. One part is volatilized by the heat of the high-pressure gas (190° F. on the day of the writer's visit), carried with the gas into the water-cooled coils, and again condensed, thence it is carried to the accumulator tank with other condensate. A second part of the atomized naphtha is probably carried mechanically into the upper pipes of

the coil by the flow of gas, where it settles out, owing to the slower rate of flow, and carries with it other condensable vapors. The third part, which is neither vaporized nor carried mechanically into the upper members of the coil, goes to the bottom of the header and flows with the gas through the bottom pipe and blends with the condensate and naphtha in the discharge header, while still under maximum pressure. The mixture then flows to the accumulator tank and thence is trapped into storage tanks.

The quantity of naphtha injected into the header is calculated to be somewhat less than is needed to bring the mixture to the gravity desired, the balance being added, in this plant, to the partly blended stock in the make tank, which is also held under pressure. Another feature of the practice at this plant is that the pressure on the blended stock is reduced slowly to avoid violent boiling or weathering. This is accomplished by holding a pressure of 50 or 60 pounds on the make tank while the output of the plant is being transferred to it during a day or shift. At the end of that period another tank is put into service and the pressure on the tank containing the day's "make" is slowly relieved, while the stock gradually acquires approximately the temperature of the atmosphere. At this point the blend is transferred to storage tanks or placed in tank cars for shipment. For each 100 gallons of condensate produced 77 gallons of naphtha is pumped into the coils, which lowers the gravity of the condensate from 90° to 96° B. to between 70° and 76° B.; later, in the "make" tank, enough eastern naphtha, with a gravity of 58° to 60° B., or California distillate, with a gravity of 48° B., is added to form a blend of the desired quality.

At another plant a practice similar to the one just described was adopted, except that the naphtha was injected into the hot-gas line at a point just beyond the oil separator and 40 or 50 feet ahead of the coils, the naphtha thus traveling with the gas through the coils and on to the accumulator tanks. This plant, although making 9 gallons of condensate per thousand feet of gas treated, as measured in the accumulator tanks, had by the old method of blending been able to market only 2.5 gallons. By the adoption of hot blending it was able to market 3.7 gallons from each thousand feet of gas treated. The loss, however, is still extremely high, and it is probable that an entire readjustment of pressures and temperatures throughout the plant would show better returns and smaller losses.

POSSIBLE IMPROVEMENTS IN BLENDING METHODS.

No set of rules can be given or standard methods of blending described that would even approximately cover all conditions, but there are methods and practices that if adopted by individual plants would have marked advantages and show a decided saving of condensate.

The problems of each plant must necessarily be taken up separately and a study made of the properties and characteristics of the condensate formed, such as the gravity, the vapor tension, and the proportions of the different "cuts" and the hydrocarbons they contain. That these vary widely is shown by the different pressures and temperatures necessary to precipitate the condensates, also by the vapor tensions or wildness of different plant products. The point at which blending is done should be given attention, to find whether the best results are obtained by blending in storage tanks, in make tanks, in accumulator tanks, or in coils, also the effects of release of pressure and rise in temperature should be studied to find whether sudden lowering of pressure and rise in temperature does not cause undue losses. Blended products are at many plants placed in storage tanks which are not protected from the sun and a quick rise in temperature is to be expected. The color an exposed tank is painted, has a direct bearing on the amount of heat absorbed from the sun's rays and taken up by the contents. Releasing the pressure on the condensate slowly, or holding it under a low pressure and storing it in insulated tanks has, at a number of plants, been found to decrease losses.

Refining companies have found that storing the lighter distillates in tanks with the water-sealed top, painted glossy white, show reduced losses well worth the expense of construction and operation of this system of storage.

LOSSES OF CONDENSATE IN WEATHERING AND SHIPPING.

Plant operators, in reporting losses of condensate, often use as a basis the total amount of condensate collected and measured in the accumulator tanks before blending, and while still under pressure, which is obviously the wrong place to make such an estimate, because such measurement is taken during treatment and not at the final stage of production. The condensate in the accumulator tank, because of the temperature and pressure, contains some dissolved gas and fractions of the hydrocarbon group which it is impossible to hold under normal atmospheric conditions, and which should not be counted as loss when computing the plant production.

The writer, in order to form an accurate idea of the losses at different plants, and as far as possible to use the same basis in estimating these losses, has obtained from the plants listed the quantity of condensate actually stored in tanks, either blended or unblended as the practice indicated. With this quantity as a basis estimates of the losses in further operations, such as weathering, pumping to loading stations, loading in cars and shipping, are computed.

In Table 2 (p. 29), the column headed "Daily production, gallons," represents the number of gallons that were actually marketed by the different plants listed, as nearly as these figures could be arrived at, and is net production after all losses are deducted.

CALIFORNIA PRACTICE.

California plants, in general, trap or blow the product of the accumulator tanks directly into storage tanks without blending and measure the make in the storage tanks. As these tanks are seldom held under pressures greater than 5 to 15 pounds, weathering goes on continually and causes an unknown loss, only the weathered product being measured.

At plants where the raw condensate is pumped from the storage tanks into the crude oil storage tanks of purchasing companies, under this method of calculating losses the results show no loss except that due to weathering while the condensate is being held in plant storage, the product being sold on the gage readings taken in the storage tank at the compression plant.

Companies shipping raw condensate in automobile trucks distances of 2 to 40 miles report losses in loading, transportation, and unloading of 2 to 7 per cent. Those delivering their product through pipe lines 1 to 40 miles long report losses of 1 to 6 per cent, depending on the length of the lines, the amount of leakage from them, and the pressure necessary to force the liquid through.

EASTERN PRACTICE.

Many plants in the eastern fields ship raw condensate by pipe line and trucks, as in California practice, with losses the same or slightly greater in amount than those quoted, owing to the raw products having higher gravities and vapor tensions. One large oil company has recently laid pipe lines to a number of the fields in northern and western Pennsylvania for the purpose of collecting the raw condensate produced in those fields and which was formerly hauled to market in trucks. Well-constructed pipe lines will undoubtedly minimize losses from handling condensate produced in this district.

OKLAHOMA PRACTICE.

Casing-head gasoline producers in Oklahoma estimate the total loss as varying between 10 and 40 per cent. The losses during weathering of the blended product run from 10 to 20 per cent, depending on the gravity of the raw product and the vapor tension of the blend. Often heating with steam is necessary, before loading the condensate into tank cars, to bring the vapor tension within the limits required by the railroad shipping rules, especially in cold weather. When weathering will not bring the blended stock to the desired condition.

The loss in this field due to transferring the product from the plant storage tanks to loading or blending stations varies from 2 to 7 per cent, and in loading from a rack to cars, between 1 and 5 per cent.

The loss during shipment in standard tank cars is variously given as being between 2 and 10 per cent, with an average of approximately 6 per cent, the loss depending much on the distance and length of time used in haulage, the atmospheric temperatures encountered, and the condition of the tank used for shipment.

The so-called thermos cars, an insulated tank car, have given very satisfactory returns on their cost to certain producers using them, who report a maximum outage (loss in transit) of $2\frac{1}{2}$ per cent when used for long shipments in hot weather, and report instances of no outage on short hauls in moderate, rainy, or cold weather. The railroad rules governing shipments in insulated cars are more in favor of the shipper in regard to vapor pressures, allowing 15 pounds as the maximum in place of 10 pounds as in standard cars.

The losses in blending and shipping in the Mid-Continent field may be generalized as follows:

	Per cent.
Weathering.	5 to 20
Transferring to loading station.	2 to 7
Loading in car tanks.	1 to 5
Shipping in standard cars.	2 to 10
Total losses.	10 to 42

Plants treating gas that contains large proportions of the lighter fractions and using pressures and temperatures that will precipitate these fractions produce the "wildest" condensate and in consequence suffer the greatest losses. As the converse of this practice a single-stage plant (No. 76 in the tables) in the Mid-Continent field, mentioned in several places throughout this paper, produces a condensate having a gravity of 79° B. and a vapor tension of about 5 pounds that is shipped in standard tank cars with a total loss of 2 to 3 per cent, including the losses from being transferred several miles through pipe lines to the loading racks and from loading into the cars.

NAPHTHA USED AS BLENDING STOCK.

To form an ideal motor fuel, the distillate or naphtha used in blending should be one that will give the mixture a uniform series of fractions between the temperatures at which distillation begins and finishes, with none of the fractions with boiling points so high as to cause incomplete combustion and carbon deposits in motor cylinders.

To blend and weather condensate to correspond with the above conditions is possible, but such practice, because of the great waste and expense, is followed only in blending special gasolines for engine or speed tests. Also, in making straight refinery distilled gasoline, because of the increased demand for motor fuel, more and more of the heavier distillates have been cut into the motor-fuel fractions, causing a lower gravity and a higher end point.

Rittman, Dean, and Jacobs^a have shown clearly the differences in still-run and blended gasolines (see fig. 13) as they are put upon the market. They state that the blended casing-head products have larger percentages distilling below 50° C. but have longer distillation ranges, which tend to make the slope of the temperature-percentage curves for these gasolines flatter than those of straight refinery products. They also state that any gasoline having an unusually large distillation cut below 50° C. and with considerable percentages distilling within the temperature ranges of 150° to 175° C. and 175° to 200° C., and being deficient in constituents boiling at intermediate

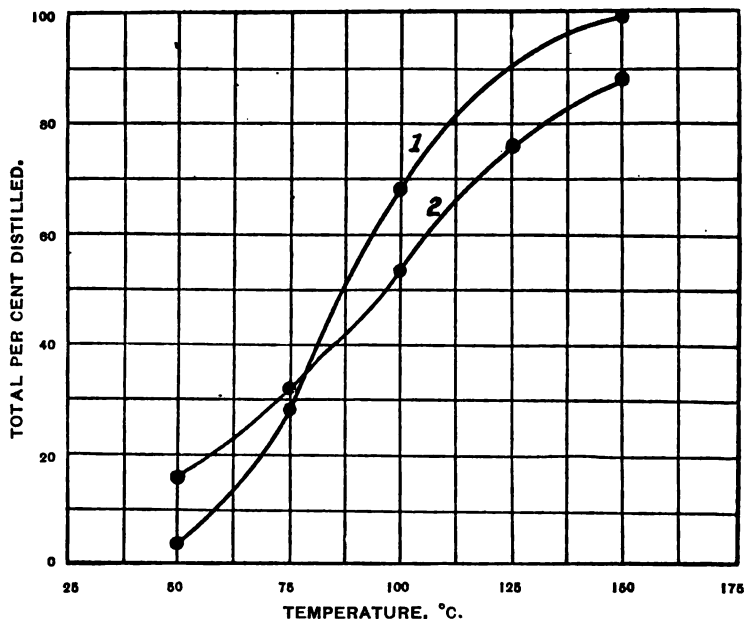


FIGURE 13.—Curves showing volatility ranges of refinery and of casing-head gasoline. 1, refinery gasoline; 2, casing-head gasoline. The flatter slope of the curve for casing-head gasoline shows that the content of both low and high boiling constituents is greater in the blended gasoline. After Rittman.

points of the distillation, may be classed as one of these blended products.

The naphthas or distillates being used for blending are those fractions that distill from crude oil after the cuts marketed as "straight still-run" gasoline have distilled off. The naphthas made from eastern and Mid-Continent crudes range in gravity from 46° to 60° B., whereas those made from the asphaltic base California crude oils range between 42° and 52° B. The difference in the eastern and western distillates is due to the fact that the crude oils in the different fields differ in character, having paraffin, asphaltic, or mixed bases.

^a Rittman, W. F., Dean, E. W., and Jacobs, W. A., Physical and chemical properties of gasolines sold throughout the United States during the calendar year 1915: Tech. Paper 163, Bureau of Mines, 1916, p. 71.

The eastern and the California naphthas used in blending have approximately the same end points, although the gravities differ 7° to 10° B.; also the blends formed have different gravities, although the end points, power developed per gallon, and the completeness of combustion of the mixtures are practically similar. The differences in the specific gravities of the various cuts of similar end points from the different crudes decreases as the cuts become lighter.

Mid-Continent crudes having mixed bases vary between California and Pennsylvania crude, and have gravity and end point ratios between the two extremes stated above.

Certain companies in buying blended gasoline specify that the product shall have a gravity of not less than 67° B. and an upper end point not more than 400° F., which will require that naphtha with a gravity of about 55° B., if from Mid-Continent crude, or 48° B., if from California, be used in making the mixture.

Numerous blending plants, however, use distillates with as low gravity and as high end point as the kerosene fractions, and, as far as is known, find no trouble in marketing such blends. In using naphthas for blending it has been found that the heavier naphthas give better results than the lighter ones in lowering the vapor tension of the mixture, for equal quantities put in, the heavy fractions having a tendency to "hold down" the light fractions.

PROPORTIONS IN BLENDS.

In general it may be stated that blended gasoline usually consists of a mixture of half casing-head gasoline and half naphtha or distillate, but the proportions vary, depending upon the gravity and vapor tension of both constituents, blending being carried to a point, in conjunction with weathering, that brings the product within the shipping rules and shows maximum profits to the producers.

STRATIFICATION OF BLENDED GASOLINE.

In many quarters belief has been expressed that in blended gasoline the light condensate fractions separate from the heavier distillate fractions, causing stratification. The writer could find no direct evidence that such stratification takes place, and interviewed many operators and blenders who had made various tests and were unable to find such a condition. It is true that owing to change of temperature, in a closed tank, the lighter fractions at times vaporize and condense on the sides of the container and drain down, floating in a thin layer on top of the liquid. This condition may have given rise to the belief regarding stratification, but, as shown, is not due to separation of the two or more blended constituents through differences in their gravities. All fractions of petroleum oils are gen-

erally considered as soluble, one in the other, and a blend of two or more fractions such as naphtha and condensate should not separate or stratify. All evidence obtainable indicates that no such stratification actually takes place in blended motor fuels through the difference in specific gravity of the members blended. A test made on a California blended product and reported to the writer showed no separation. The blend, which was a small quantity of condensate with a gravity of 105° B. and a large quantity of distillate with a gravity of 48° B., was placed in a 10-barrel tank and tested after standing one week without being disturbed. Samples drawn from the top and bottom had specific gravities differing only 0.07° B. This blend found a ready market as fuel for motor trucks.

The naphthas used and the blends marketed at the present time depend to no small extent on the market conditions of the heavier distillates. Naphthas that can be obtained in quantity easily and regularly, thus insuring a steady supply, are often chosen in preference to a more perfect blending stock, supplies of which can not be depended upon.

COSTS OF COMPRESSION PLANTS.

The widely varying conditions under which compression plants are being installed, both as to situation and the machinery and the steel markets, make estimates of the costs of plants so uncertain that the subject will be undertaken with the idea of showing the costs of plants recently installed, of which the writer has knowledge, rather than to attempt to estimate costs in general for present or future installations.

An operator in the Mid-Continent field who has built and is running three plants computes plant construction costs on a unit basis and gives the costs of one unit that will treat 400,000 to 500,000 cubic feet of gas daily, as follows: One single-stage unit, compressing the gas to a pressure of 75 or 90 pounds, \$8,000 to \$9,000; one two-stage unit compressing to 200 or 250 pounds, \$15,000 to \$18,000. Vacuum pumps at the compression plants are included in this estimate, but not gathering lines with their pumps, or the expansion engines that are used at the plants. On this basis, a 1,000,000-foot plant compressing gas to a pressure of 250 pounds would cost approximately \$36,000, or \$36 per 1,000 feet of capacity.

The expense of construction and equipment of a plant compressing 1,250,000 cubic feet of gas daily to 250 pounds, put into commission in June, 1916, was stated to be \$36,570, divided as follows:

Cost of compression plant with a capacity of 1,250,000 cubic feet.

Machines, engines, compressors, water pumps, and air pumps and tanks.....	\$18,240
Pipe and fittings, engine and compressor connections, cooling coils and double-pipe coils.....	1,534
Building compressor room with steel frame, cooling tower, accumulator tank and storage housing, auxiliary engines and pumps.....	6,756
Gathering lines.....	3,797
Tankage.....	1,105
Gas traps.....	700
Electric plant.....	395
Labor, carpenter work; pipe-fitting; concrete, etc.; setting engines.....	4,043
Total.....	36,570

No expansion set is included in this estimate, but when the capacity of the plant was doubled later in the same year a simple single-stage compressor was installed as an expansion engine and is used to expand all of the gas treated, or 2,500,000 cubic feet. The construction of the first half of the plant shows a cost of \$29 per 1,000 feet capacity. The entire cost of the plant after the original capacity was doubled and an expansion engine installed is approximately \$60,000, or \$24 per 1,000 feet capacity.

Another plant with a total capacity of 2,500,000 feet, built during the same period, using the same pressures and very similar to the plant described above, in units and "hook-up" (compressor and engine drive), but using a drilling engine as an expander, cost \$55,000, or \$22 per thousand feet capacity.

The cost per 1,000 feet of capacity of plants treating small quantities of gas, 100,000 to 250,000 cubic feet daily, is relatively higher; instances having come to the attention of the writer of costs of \$40 or \$50 per 1,000 feet capacity for plants of that size.

One small plant—a 250,000-foot plant compressing gas to 250 pounds—including an expansion engine, cost \$11,000, or more than \$44 per 1,000 feet of capacity.

Plants treating small quantities of gas under pressures obtained by single-stage compressors and having simple cooling systems, such as are found in many eastern fields, notably Sistersville, W. Va., cost much less than is indicated by the above estimates.

No estimate of costs of gathering systems, with vacuum stations and booster compressors, can be made, as the conditions vary from a few hundred feet of 6-inch lines to lines of 8 and 10 inches diameter extending 5 to 10 miles from the plant and having as many as 30 pumps and "booster" machines forcing the gas through the mains and maintaining low pressures on the wells.

MINIMUM PLANT CAPACITY AT WHICH GAS CAN BE TREATED PROFITABLY.

The question of how much gas is necessary to make the installation of a compression plant profitable often arises. This subject is approached more easily and clearly from the point of production, the quantity of gas being allowed to vary accordingly. Operators owning wells producing enough gas to produce 150 or more gallons of condensate daily can at the present price of that product well afford to install a plant, provided that no royalties have to be paid, that the gas will yield 1 gallon or more per 1,000 cubic feet, and that not more than one extra man must be kept on the pay roll. To produce this quantity of condensate under these conditions, 150,000 cubic feet of 1-gallon gas, or 50,000 cubic feet of 3-gallon gas would be profitable. In plants of this size owned and operated by oil and gas producers, often no extra help is needed, the plant being watched and taken care of by pumpers in making their regular rounds of the lease. The cost of such plants varies under average conditions between \$4,000 and \$8,000, and profitable returns on the costs of installation are shown.

With these costs as a basis and considering royalties and additional labor to run the plants, the quantities and richness of gas necessary to make an installation profitable may be estimated. Many small plants in the eastern fields are treating 75,000 to 100,000 cubic feet of gas daily, and the fact that they continued to run during times when condensate sold at 8 and 10 cents per gallon would indicate that profits under the present conditions are gratifying. The price received in August, 1916, at Sistersville, W. Va., for condensate with a gravity of 86° B., was reported to be more than 18 cents per gallon.

PLANT RECORDS.

The writer in collecting detailed plant data found that many, in fact most compression plant operators used no system of daily report sheets or records of plant operation further than making each day an estimate of the condensate produced. It is difficult to see how plants of this character can be operated intelligently, or improvements made, unless accurate records of all the more important plant functions are carefully kept and used in directing changes and experiments to improve the practice and increase the quantity and quality of the product. At fully one-half of the plants visited no attempt was made at keeping data of any kind excepting records of the production, and only a limited number of those keeping accurate and detailed records made any use of them; or had tried to improve either the operation or the product. For instance, the pressure of 250 pounds is almost universally used as the ultimate pressure at plants throughout the western fields, because other operators use

it and because the machines and pipe fittings are designed for that pressure, the actual qualities of the gas being treated not being considered. At one plant that had been using a pressure of 250 pounds, it was found that the engines gave less trouble when the pressure was reduced to about 200 pounds and that no less condensate was produced, showing that the higher pressure had not been used because it was best suited to the gas but because it was standard for the machines in use.

In every plant the best pressures and temperatures to use must be found by trial and experiment, but without records of results and conditions improvements will be slow in coming. The accompanying form shows the daily report sheet used by a progressive California operator. Many of the records are made by recording gages and thermometers, the charts being filed for reference and comparison with the report sheet. At any sign of a disturbance of any plant function, additional information is gathered, such as the specific gravity of the gas before entering and after being discharged from the plant and after each step in its treatment. The quantities of condensate precipitated and collected at each accumulator tank and its specific gravity are also found useful in locating plant disturbances or irregularities. Records of temperatures of the gas, at each change of pressure and after each set of coils is passed or each fraction of condensate is removed, should be kept. Records of cooling water and atmospheric temperatures, in conjunction with other records, may show either the cause or the effect of changes in the gas or in plant conditions. Although the cooling of gas in coils and of water in towers has been practiced for years, many casing-head gasoline plants have installed only the most primitive and least efficient systems, and the lack of records and data obscure the fact that poor results are being obtained from their use.

Records of engine speeds and other purely mechanical data, such as the number of hours machines are shut down and the reasons for such delays, are of use in determining costs, plant efficiency, and the efficiency of men in charge of plants or the machines, as well as the principal causes of trouble and weakness of any machine or part.

Accurate plant records are also valuable in cooperating with operators of other plants in an endeavor to improve general plant practice and operation. It was noticed in districts where friendly cooperation existed that the practice in general in that district was more modern and that the operators and men in the plants had a broader understanding of the process as a whole.

The measure of success in most compression plants has been considered only from a narrow viewpoint, the improvements possible and the waste of condensable vapors contained in the gas being overlooked.

Report sheet used at compression plant in California.

DAILY REPORT. On tour..... First engineer..... Third engineer..... Date.....
 Gasoline Plant C, No. 1. Off tour..... Second engineer..... Fireman.....
 Gas from wells No.....

MACHINE REPORT.

Number of machine.

SHUT DOWN.	1		2		3		4		5		6		7		8		9		10	
	Hours.	Min. utes.	Hours.	Min. utes.	Hours.	Min. utes.	Hours.	Min. utes.	Hours.	Min. utes.	Hours.	Min. utes.	Hours.	Min. utes.	Hours.	Min. utes.	Hours.	Min. utes.	Hours.	Min. utes.
For shift.....																				
For month forwarded.....																				
Total for month.....																				

SPEED—REVOLUTIONS PER MINUTE.

OIL USED—GALLONS.

Machine No.	1	2	3	4	5	6	7	8	9	10	Steam cylinder.	Journal.	Compression and gas cylinder.	Glycerin.
Time of reading.....	3													
For month forwarded.....	6													
Total for month.....	12													
Total for year.....														

For shift.....
 For month forwarded.....
 Total for month.....
 Total for year.....

GAS TEMPERATURES—INCHARGE FROM LOW AND HIGH PRESSURE CYLINDERS.

Machine No.....	1		2		3		4		5		6		7		8		9		10	
	Inter-mediate.	High.	Inter-mediate.	High.	Inter-mediate.	High.	Inter-mediate.	High.	Inter-mediate.	High.	Inter-mediate.	High.	Inter-mediate.	High.	Inter-mediate.	High.	Inter-mediate.	High.	Inter-mediate.	High.
Time of reading.....	3																			
	6																			
	9																			
	12																			

EXPANSON SET—TEMPERATURES AND PRESSURES.

TEMPERATURES AND PRESSURES.

	At-mos-pheric tem-perature.	Cool-ing water.	Scrubber.		High-pressure inlet.		Intermediate expansion.		Discharge to lease.		Bess. coil No. 1.		Coil No. 2.		Coil No. 3.		Number of coils cooled by intermediate expansion.		Number of coils cooled by low-pressure expansion.	
			Pres-sure.	Tem-perature.	Pres-sure.	Tem-perature.	Pres-sure.	Tem-perature.	Pres-sure.	Tem-perature.	Inlet.	Out-let.	Inlet.	Out-let.	Inlet.	Out-let.				
Time of reading.....	3																			
	6																			
	9																			
	12																			

PRODUCTION REPORT.

REMARKS:

	Gal-lons.	Grav-ity.	Gal-lons.	Grav-ity.	Boilers cleaned. Boilers repaired. Furnace repaired. Water used.
Low pressure.....					
High pressure.....					
Coil 1.....					
Coils 2 and 3.....					
Exhaust.....					
For shift.....					
For month forwarded.....					
For month total.....					
For year forwarded.....					
For year total.....					
Certified correct by..... First Engineer.					
Sheet No.....					

The staff of the Bureau of Mines receives many letters asking information regarding the manufacture of gasoline from natural gas, which they willingly and gladly answer, but in most of these letters the data regarding both the gas and the operation of the plant are so meager that answers must be of a very general character and are probably as unsatisfactory to the correspondent as to the writer.

SUMMARY.

In the following paragraphs some of the more important factors relating to natural-gas gasoline and its production by the compression process are briefly discussed.

TESTING NATURAL GAS TO DETERMINE ITS SUITABILITY FOR MAKING GASOLINE.

The various hydrocarbons, and also the impurities, found in natural gas as it comes from oil or gas wells, have a direct bearing on the plant practice and treatment that will yield the most condensate. The more complete and thorough the tests made on the gas to determine its composition and physical characteristics are, the less chance there will be of those interested building and operating a compression plant that is not best suited for treatment of that particular gas.

Thus far the plants installed have been generally of standard design and equipment using the maximum safe pressures for which standard machines and fittings were built and temperatures obtainable by simple methods of water cooling, little consideration being given to the qualities of the gas to be treated.

Gas testing as followed at the present time is done only to determine if the gas can be profitably treated, and, if found so, a plant of general standard design is put in operation. It must be admitted that these plants as a whole, throughout the United States, have proved financially successful, but as a rule such success is due, in the writer's opinion, more to the fact that only the rich gas has been taken for treatment than to careful plant design and operation. The great increase in production at a few of the plants where the operators have studied the gas being treated and installed equipment best suited to its composition and characteristics indicates that gross waste is taking place at many plants of standard design. As more is learned of the best methods of treating natural gas in compression plants, gas of lower gasoline content can be and will be used in such plants.

At many plants visited no gas tests of any kind had been made since the original tests to determine whether the gas was rich enough in gasoline to warrant treatment. With the aging of the wells, the extension of gathering lines, and the installation of vacuum pumps, which often draw air into the gas lines, it is hard to believe that no variation in treatment was necessary if the best results were desired.

Gravity tests of the gas used should be made from time to time at all plants. The results will indicate any changes in composition and usually whether air has been taken into the line. This test, if made at different points in the treatment and on the treated gas may also indicate either a change in the character of the gas or that some part of the plant is not working as usual. Other tests, such as absorption and compression tests and analyses, made and recorded at regular intervals, have been of value in determining sources of trouble and indicating the need of experiments and of plant changes.

Experimenting with the entire plant or one complete unit by changing the temperatures and pressures and recording the results may lead to better recovery or a better product.

PRESSURES AND TEMPERATURES.

Gas from wells that are being and often have been gas-pumped for years, and are held under high vacuums is composed largely of the heavier vapors that would, unless vacuums were used, remain as liquid in the oil, and in treating such gas extreme pressures and temperatures are not necessary.

In eastern fields, where these conditions are most often found, single-stage plants working at a pressure of about 100 pounds and using such temperatures as can be obtained in submerged coils cooled by the natural temperatures of well or creek waters, give satisfactory recoveries and produce condensates with a gravity and vapor pressure as high as can be handled, either blended or unblended. In the same fields, however, plants treating gas from old wells not held under vacuum have found that not enough of the vapor carried by the gas can be condensed at pressures lower than 300 pounds to be profitable. The condensate produced at that pressure was exceedingly wild and in order to effect a maximum saving required blending as early in the process of precipitation as possible. It appears from the above facts that gas taken from wells held under high vacuum carries portions of the higher-boiling fractions, distilled from the oil under reduced pressures, that would otherwise have remained in the oil in the sands. The removal of the lighter fractions by this method has less effect on the gravity of the refined oil than would at first seem probable, because a marked percentage of these vapors undoubtedly came from oil left in the sands which in all probability will never be extracted, and also because the oil production from many small wells held under high vacuums is stored for days, and even weeks, in tanks, exposed to changes in atmospheric temperature, during which time the lighter fractions are lost to a greater or less extent. Under these conditions, relieving the oil of its lightest vapors before it is exposed to evaporation, or while still in the sands underground, would save these valuable products.

In the newer fields, in which the gas is still produced under widely varying rock pressures, a maximum plant pressure of 250 pounds is almost universally used, and refrigeration has often been found to increase production 10 to 50 per cent.

Besides the usual cooling with water, at some plants the gas is also cooled in heat interchangers, while still at the maximum pressures used, with expanded gas. The dry compressed gas is expanded adiabatically in the power cylinder of a steam engine, its temperature being lowered at times to -100° F. In the heat interchanger the high-pressure gas is reduced to temperatures as low as -10° F., which causes vapors not condensed in the water-cooled system to precipitate. It is the writer's opinion that many plant operators are overlooking gas expansion as a means of increasing the net production of their plants.

The treatment of natural gas for gasoline is unlike those manufacturing processes in which the treated material may be stored and treated a second or third time after the first extraction or concentration of the desired portions, because the gas, after once coming to the surface, must be kept moving until treated and used as fuel or wasted to the atmosphere. Thus marketable fractions of condensate left in the gas after treatment are practically entirely wasted.

CONDENSATE.

The gasoline carried in natural gas and precipitated at different points in the treatment consists mostly of pentane and hexane, the fifth and the sixth members of the paraffin series, smaller proportions of heptane, the seventh member, and decreasing percentages, if any, of propane and butane, the third and fourth fractions. In condensates produced at high pressures and low temperatures, probably some propane and butane are present and with dissolved gas cause the high vapor tensions of some plant products. The amount of dissolved gas is probably of no importance, as far as volume is concerned, but there seems to be little reason to doubt that when the pressure on the condensate is relieved the gas has a decided tendency to cause boiling and agitation of the liquid, which, with boiling of the propane or the butane, causes losses not only of these constituents but also of some of the heavier members during weathering.

The gravity of the plant products as they come to the accumulator or the "make tanks" varies between 70° and 96° B., and the vapor tension, from 5 to 40 pounds.

The gravity and the vapor tension of the condensates as collected in the accumulator tanks of the successive stages become higher as the higher pressure and the lower temperature changes are reached. The products range from line drip or distillate with a gravity of 55° B., produced at atmospheric temperature and pressure, to condensate

with a gravity of 105° B., produced in the accumulator tank at the expansion-engine exhaust, at -40° F., the gas having been reduced to a pressure of 10 pounds.

Experiments and the equipment of recent plants indicate that to remove the condensate from contact with the gas as soon as possible after precipitation and collection is the best practice. This is accomplished by the use of small automatic traps, which drain the liquid from the accumulator tanks as soon as collected. The liquid then passes through pipes to "make tanks," or storage tanks, the pressure being reduced on a small quantity of condensate at each dumping of the trap with the least possible agitation and consequent boiling. This method reduces transfer losses and those from sudden lowering of pressure on large amounts of condensate at one time. The automatic traps are used in transferring either raw or blended products from accumulator tanks to storage or "make" tanks at lower pressures.

BLENDING.

Although some casing-head gasoline is shipped and used without being blended, most of it is mixed or blended with naphtha of lower gravity and vapor tension before reaching the consumer.

Condensate, although at times shipped unblended, is in the most modern plants and the latest practice blended as soon as possible after being formed, or even while in the process of precipitation. Some operators still ship their product partly blended or reduced in gravity and vapor tension to blending stations or refineries, but the general practice is to blend at some stage of precipitation or storage at the plant.

Blending at the plants is done in the storage tanks, the "make tanks," and the accumulator tanks, and at times in the coils while the condensate is still in process of precipitation and in contact with the high-pressure gas. Operators using these methods claim definite increases in production for each successively earlier point in the process of cooling and precipitation in the high-pressure units at which blending is accomplished.

Naphthas having an end point of approximately 400° F. are in general use as blending stocks, but at some plants where regular supplies of this stock could not be obtained, distillates having the end points and gravities of kerosene are used.

Some blending companies use with the usual naphthas small quantities of "straight" still-run California gasoline, specific gravity 58° B., and Mid-Continent and eastern grades, specific gravity 66° to 68° B., in order to increase the proportions of those hydrocarbons of which the naphtha and the condensate contain only small percentages.

THE ADVANCEMENT OF THE INDUSTRY.

Since the first commercial gas compression plants were established, about 15 years ago, in the eastern oil fields, marked advancement has been made in the mechanical and commercial phases of the natural-gas gasoline industry.

Up to about five or six years ago, most of the plants consisted of the simplest forms of gas pumps, single-stage compressors, and cooling coils, were operated only on rich casing-head gas that would produce 4 to 6 gallons of condensate, and had a capacity of not more than 200,000 or 300,000 cubic feet daily.

At present plants are in operation treating 6,000,000 to 9,000,000 cubic feet daily of gas yielding as low as 1 gallon of condensate per 1,000 cubic feet, using pressures of 250 and 300 pounds per square inch in two stages of compression, with elaborate systems of cooling the gas with water before compression and after each stage of compression. The water used is cooled below normal temperatures by induced aeration and radiation.

In some plants the gas is further cooled by expanding the dry treated gas through the cylinders of an expansion engine and using the cold expanded gas to cool the high-pressure gas from the water-cooled coils. Temperatures as low as 0° F. are often obtained, causing the precipitation of nearly all the condensable fractions commercially valuable for making gasoline.

FORMULAS AND TABLES GOVERNING THE FLOW OF GAS IN PIPE LINES.

Formulas governing the flow of gas in pipes have been worked out by Weymouth and discussed by him in a paper^a published by the American Society of Mechanical Engineers. These formulas with that part of Weymouth's report that relates to the flow of gas in pipe lines are given in the following:

TRANSMISSION OF NATURAL GAS.

By THOMAS R. WEYMOUTH.

In the design of pipe lines for the transmission of natural gas from the field to the points of consumption it is necessary to make use of a formula expressing the relations to each other of the quantity and initial and final pressures of the gas, and the diameter and length of line. Many such formulas have been proposed giving widely differing results. In nearly all of them the flow is stated as varying as the square root of the fifth power of the pipe diameter, and either the coefficient of friction is considered constant, or a different coefficient is given for each diameter of pipe. This serves well enough where the diameter is known and any one of the other quantities expressed by the formula is desired, but is somewhat awkward when it is desired to ascertain the diameter of line necessary to meet the other given conditions.

The author has derived a new formula which he believes expresses the relationship of the quantities involved even more closely than any heretofore offered. It is based on isothermal flow, and the variation in the value of the coefficient of friction is provided for without complicating the formula, yet permitting the required diameter of line to be ascertained readily.

The expression for the initial velocity of any gas flowing in a pipe is given by Unwin^b as

$$(1) \quad u_1 = \sqrt{\frac{gC \bar{T}m(P_1^2 - P_2^2)}{fl P_1^2}}$$

u_1 =initial velocity, in feet per second.

g =acceleration due to gravity.

C =thermodynamic constant of the flowing gas = $\frac{PV}{T}$

T =absolute temperature of gas.

m =hydraulic mean radius of the pipe = $\frac{D}{4}$.

P_1 =absolute initial pressure of the gas, in pounds per square inch.

P_2 =absolute final pressure of the gas, in pounds per square inch.

f =coefficient of friction.

l =length of line, in feet.

^a Weymouth, T. R., Problems in natural-gas engineering: Trans. Am. Soc. Mech. Eng., vol. 34, 1912, pp. 185-234.

^b Unwin, W. C., Transmission and distribution of power from central stations, 1892, p. 259.

Let

C_a = thermodynamic constant for air.

G = specific gravity of flowing gas, air = 1.0.

D = diameter of pipe, in feet.

d = diameter of pipe, in inches.

$$\text{Then } C = \frac{C_a}{G}, \text{ and } m = \frac{D}{4} = \frac{d}{48}$$

Hence

$$(2) \quad u_1 = \left[\frac{g C_a T (P_1^2 - P_2^2) d}{48 G f P_1^2} \right]^{\frac{1}{2}}$$

If q = quantity of gas flowing per second; based on absolute pressure and temperature of P_o and T_o ,

$$A = \text{area of cross section of pipe in square feet} = \frac{\pi d^2}{4 \times 144}$$

Then

$$(3) \quad q = u_1 A \frac{P_1 T_o}{P_o T} = u_1 \left(\frac{\pi d^2}{4 \times 144} \right) \frac{T_o P_1}{P_o T} \left(\frac{\pi}{576} \right) \frac{T_o}{P_o} \left[\frac{g C_a (P_1^2 - P_2^2) d^5}{48 G T f l} \right]^{\frac{1}{2}}$$

If

Q = flow in cubic feet per hour, based on P_o and T_o , and

L = length of line, in miles,

Then

$$l = 5280 L$$

and

$$Q = 3,600 q$$

$$(4) \quad Q = \frac{3,600 \pi}{576 \sqrt{48} \times 5280} \frac{T_o}{P_o} \sqrt{g C_a \left[\frac{(P_1^2 - P_2^2) d^5}{G T f L} \right]^{\frac{1}{2}}}$$

Taking $g = 32.17$ and $C_a = 53.33$,

$$(5) \quad Q = 1.6156 \frac{T_o}{P_o} \left[\frac{(P_1^2 - P_2^2) d^5}{G T f L} \right]^{\frac{1}{2}}$$

Experiments on the flow of air in pipes of different diameters indicate that the coefficient of friction f is a variable, decreasing with increasing diameters of line. A great many such experiments have been collected and published in "Compressed Air," by Elmo G. Harris, from which, by the use of equation 5, the coefficients of friction have been computed and plotted in figure 14.

In the reports of these tests no statements were made as to the method of measuring the quantity of gas flowing, and it is quite probable that many of the results are inaccurate in this respect. Notwithstanding this, however, the nature of the variation of f with the diameter is evident, and the curve represented by the equation

$$f = \frac{0.008}{\sqrt[3]{d}}$$

gives a fair average of the loci of the points plotted. Inserting this value of f in equation 5, the expression becomes

$$(6) \quad Q = 18.062 \frac{T_o}{P_o} \left[\frac{(P_1^2 - P_2^2) d^{5\frac{1}{4}}}{G T L} \right]^{\frac{1}{2}}$$

Equation 6 is the general formula for the flow of gas in long pipe lines.

In 1901 Forrest M. Towl conducted an extended test on an 8-inch line, 70 miles long, supplying gas to Buffalo, the results of which were published in a bulletin issued by Columbia University in 1911. Previous to the test the line had been repaired and tested for leaks, and was known to be practically gas-tight. The flow was measured by standardized Pitot tubes, which gave results accurate within less than 1 per cent. The specific gravity G of the flowing gas was 0.64, its temperature

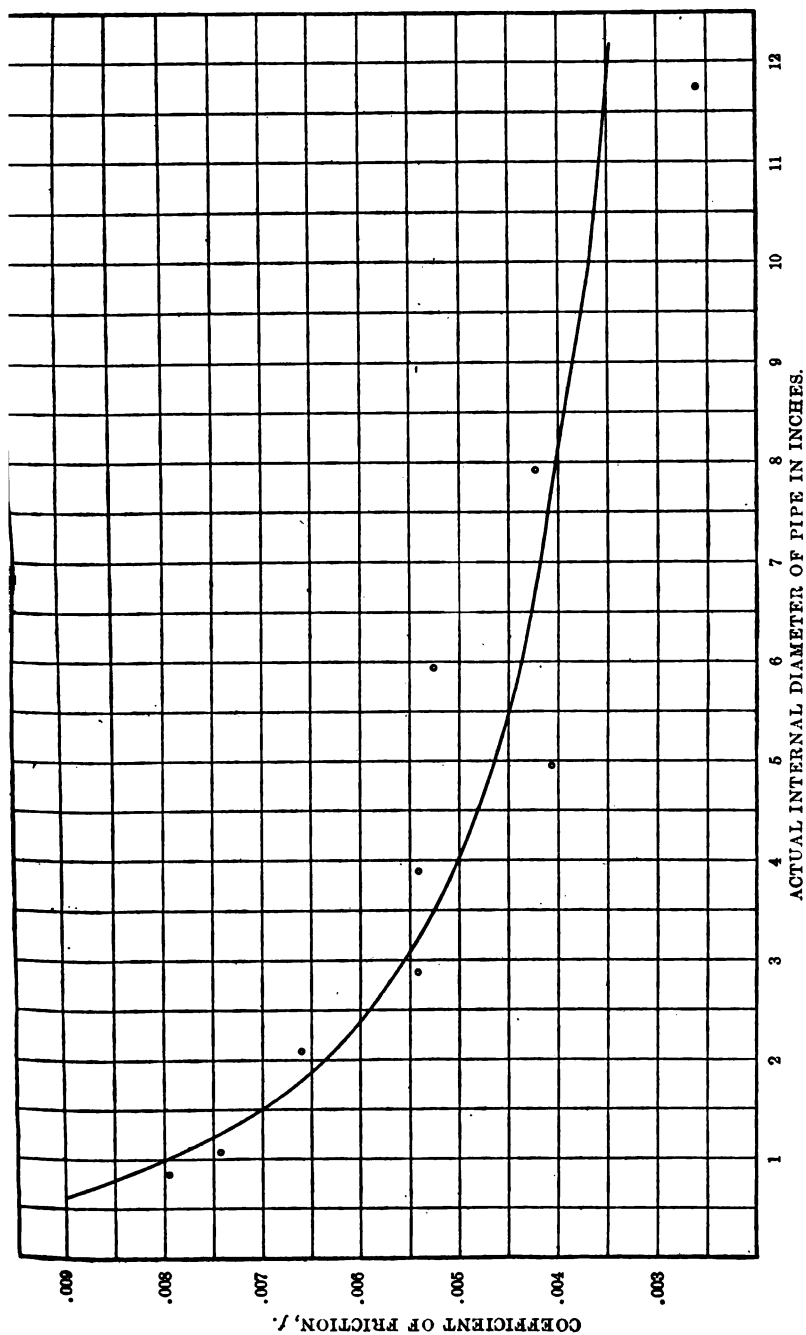


FIGURE 14.—Curve for coefficient of friction for flow of gas in pipes. Coefficient of friction / equals $\frac{0.008}{D^4}$, where D is internal diameter of pipe in inches.

32° F., or $T=492^{\circ}$ absolute. The temperature basis on which the gas was measured was 50° F., or $T_0=510^{\circ}$ absolute, and the pressure basis was 4 ounces above 14.4 pounds, or $P_0=14.65$ pounds per square inch absolute. In a length of pipe 70.32 miles long P_1 and P_2 were 210 and 41 pounds per square inch absolute, respectively. The actual diameter of the pipe was 7.981 inches, and the rate of flow by Pitot tube was found to be 221,000 cubic feet per hour.

Inserting these quantities in formula 1 and solving for flow, it becomes

$$Q=221,400 \text{ cubic feet per hour,}$$

or less than 0.2 per cent greater than the actual flow as measured.

Assuming gas standard conditions of measurement basis, namely, 60° F. and 14.65 pounds absolute pressure, and that the average flowing temperature of the gas throughout the year will be 40° F., the formula becomes

$$(7) \quad Q=28.66 \left[\frac{(P_1^2 - P_2^2) d^{5/4}}{L G} \right]^{1/4}$$

and, if an average specific gravity of 0.60 be assumed,

$$(8) \quad Q=37 \left[\frac{(P_1^2 - P_2^2) d^{5/4}}{L} \right]^{1/4}$$

Formula 8 is of practical use in designing lines for the transmission of natural gas. It is used as given, or in a transposed form, for all problems relating to single lines of uniform diameter.

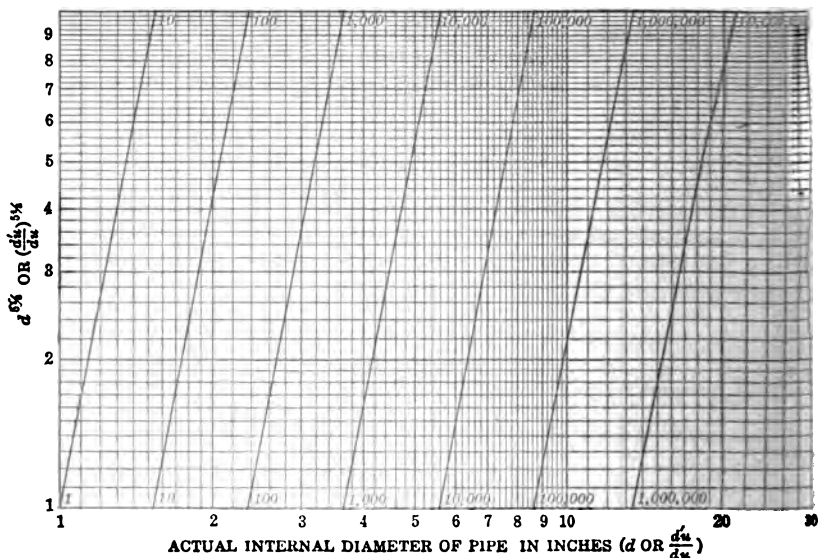


FIGURE 15.—Broken curve showing values of equivalent lengths of different diameters of pipe.

If a line is composed of several lengths, $L_1, L_2, \dots, L_n$, of diameters $d_1, d_2, \dots, d_n$, each of these lengths must be transformed into an equivalent length of one chosen diameter, by means of the formula

$$(9) \quad L_n^1 = L_n \left[\frac{d_n^1}{d_n} \right]^{5/4}$$

These equivalent lengths added together will give $L=L_1, L_2, \dots, L_n$, which is the value for L in formula 8.

Values of equivalent lengths for different diameters can be most conveniently ascertained by the use of the curves in figure 15, which consist of plots of the values of $d^{5/4}$ for varying values of d . Values taken from these curves are convenient to use directly in the pipe-line formula, equation 8, whereas they are most simply used in equation 9 as values of the $5\frac{1}{4}$ power of the diameter ratios.

TABLES.

VOLUME OF FLOW FROM DIFFERENT SIZES OF PIPE AT VARIOUS PRESSURES.

The number of cubic feet of gas of a specific gravity of 0.6 (air equaling 1.0) that will flow from the mouth of a 1-inch pipe in 24 hours is given in Table 10 following. The pressure of the container is taken as 4 ounces above an assumed atmospheric pressure of 14.4 pounds to the square inch, and the temperature of the flowing gas and the container is assumed to be 60° F. If the diameter of the pipe is other than 1 inch, multiply the discharge value given in Table 10 by the square of the actual diameter of the pipe, as found in Table 11.

TABLE 10.—Rate of flow of natural gas in pipe 1 inch in inside diameter at various pressures.^a

Observed gage pressure.			Flow, cubic feet per day.	Observed gage pressure.			Flow, cubic feet per day.
Inches of mercury.	Inches of water.	Pounds per square inch.		Inches of mercury.	Inches of water.	Pounds per square inch.	
.....	0.1	0.0036	12,390	10.17	.....	5.0	436,200
.....	0.2	0.0073	17,560	11.18	.....	5.5	456,200
.....	0.3	0.0109	21,480	12.20	.....	6.0	473,750
.....	0.5	0.0182	27,720	13.21	.....	6.5	489,840
0.05	0.7	0.0254	32,820	14.23	.....	7.0	506,920
0.7	1.0	0.0364	39,210	15.25	.....	7.5	522,010
0.11	1.5	0.0545	48,030	16.26	.....	8.0	538,500
0.15	2.0	0.0727	55,340	18.30	.....	9.0	565,970
0.22	3.0	0.109	67,910	20.33	.....	10.0	589,270
0.29	4.0	0.145	78,410	24.39	.....	12.0	633,340
0.37	5.0	0.182	87,670	28.46	.....	14.0	675,000
0.52	7.0	0.254	103,500	32.53	.....	16.0	713,550
0.74	10.0	0.3636	123,000	36.60	.....	18.0	748,650
1.02	13.75	0.50	146,220	40.66	.....	20.0	779,350
1.52	20.62	0.75	175,350	50.81	.....	25.0	845,150
2.03	27.5	1.00	201,800	61.60	.....	30.0	902,180
3.05	41.25	1.5	247,840	71.16	.....	35.0	954,820
4.07	55.0	2.0	285,130	.....	.....	40.0	989,680
5.08	68.75	2.5	316,500	.....	.....	45.0	1,036,700
6.10	82.50	3.0	344,350	.....	.....	50.0	1,072,000
7.12	96.25	3.5	370,000	.....	.....	55.0	1,106,880
8.13	110.0	4.0	393,000	.....	.....	60.0	1,137,600
8.15	.....	4.5	415,270	.....	.....	.....	.....

^a Thompson, A. B., Oil-field development and petroleum mining, Lind., 1916, pp. 578-579; quoted by Johnson, R. H., and Huntley, L. G., Oil and gas production, 1916, p. 9.

In correcting for temperature of flowing gas, where observed, of 30°, 40°, 50°, and 60° F., add 4, 3, 2, and 1 per cent, respectively. To change the result, as found by this table, to that for any other specific gravity of gas than 0.6, multiply by $\sqrt{\frac{0.6}{\text{specific gravity of gas}}}$

TABLE 11.—Multipliers for pipe of diameters other than 1 inch.^a

Diam-eter of opening.	Multi-plier.	Diam-eter of opening.	Multi-plier.	Diam-eter of opening.	Multi-plier.	Diam-eter of opening.	Multi-plier.	Diam-eter of opening.	Multi-plier.
<i>Inch.</i>		<i>Inches.</i>		<i>Inches.</i>		<i>Inches.</i>		<i>Inches.</i>	
1	0.0038	1	1.00	4	16.00	6	36.00	8	64.00
1 1/4	0.0156	1 1/4	2.25	4 1/2	18.00	6 1/2	39.00	8 1/2	68.00
1 1/2	0.0625	2	4.00	5	25.00	6 3/4	43.90	9	81.00
1 3/4	0.2500	2 1/2	6.25	5 1/4	26.90	7	49.00	10	100.00
2	0.5625	3	9.00	5 1/2	31.60	7 1/2	52.50	12	144.00

^a Johnson, R. H., and Huntley, L. G., Oil and gas production, 1916, p. 355.TABLE 12.—Variation in volume of 100 cubic feet (100 per cent) of gas at constant temperature under various gage pressures.^b

Pressure per square inch.	Volume.	Pressure per square inch.	Volume.	Pressure per square inch.	Volume.
<i>Ounces.</i>	<i>Per cent.</i>	<i>Pounds.</i>	<i>Per cent.</i>	<i>Pounds.</i>	<i>Per cent.</i>
0.....	100.0	4.....	78.6	20.....	42.5
2.....	99.1	5.....	74.6	30.....	32.1
4.....	98.3	6.....	71.0	40.....	26.1
6.....	97.5	7.....	67.7	50.....	22.7
8.....	96.7	8.....	64.7	75.....	16.5
10.....	95.9	9.....	62.0	100.....	12.1
12.....	95.1	10.....	59.5	150.....	8.9
14.....	94.3	12.....	55.0	200.....	6.1
<i>Pounds.</i>					
1.....	93.6	14.....	51.5	250.....	4.9
2.....	88.0	16.....	47.8	300.....	4.1
3.....	83.0	18.....	44.9	400.....	3.1

^b Johnson, R. H., and Huntley, L. G., Principles of oil and gas production, 1916, p. 355.

CHANGE IN VOLUME OF GAS WITH CHANGE IN TEMPERATURE.

In Table 13 following, the standard is taken at 60° F. and 14.4 inches of mercury plus 0.25=14.65 inches of mercury. Absolute zero=460° F. below freezing=488° below 60° F. The specific gravity of the natural gas is taken at 0.6, air being 1. The same 1,000 cubic feet of gas at 60° F. will measure 1,041 cubic feet at 80° and 959 cubic feet at 40°. The percentage of the decrease and increase below or above 60° F.; the specific gravity of the gas at temperatures below and above 60° F.; also weight of 1,000 cubic feet of gas and air at the different temperatures is shown. For each degree there is a change of 0.002056 in volume.

TABLE 13.—*Change in volume of 1,000 feet of air or natural gas, owing to change in temperature.^a*

Tempera- ture.	Volume of 1,000 cubic feet of gas measured at tem- peratures other than 60° F.	Loss or gain in volume.	Specific gravity (specific gravity— 0.6 at 60° F.).	Weight of 1,000 cubic feet of gas (0.6 specific gravity at 60° F.).	Weight of 1,000 cubic feet of air.
° F.	Cubic feet.	Per cent.		Pounds.	Pounds.
0	877	-12.3	0.6841	58.82	85.97
10	897	-10.3	0.6689	56.41	84.33
20	918	-8.2	0.6536	54.04	82.69
32	943	-5.7	0.6382	51.36	80.73
40	959	-4.1	0.6256	49.68	79.43
50	980	-2.0	0.6124	47.63	77.77
60	1,000	0.0	0.6000	45.67	76.12
70	1,020	+2.0	0.5879	43.78	74.48
80	1,041	+4.1	0.5763	41.96	72.83
90	1,061	+6.1	0.5652	40.23	71.10
100	1,082	+8.2	0.5545	38.56	69.55
110	1,102	+10.2	0.5442	36.95	67.90
120	1,122	+12.3	0.5343	35.40	66.26
130	1,143	+14.3	0.5247	34.10	64.62
140	1,163	+16.3	0.5157	32.47	62.98
150	1,184	+18.4	0.5067	31.07	61.33
160	1,204	+20.4	0.4981	29.72	59.69
170	1,225	+22.5	0.4898	28.42	58.05
180	1,245	+24.5	0.4818	27.17	56.40
190	1,265	+26.6	0.4739	25.94	54.76
200	1,285	+28.6	0.4665	24.78	53.12
210	1,306	+30.7	0.4591	23.63	51.48
212	1,311	+31.1	0.4576	23.41	51.16

^a Westcott, H. P., Handbook of natural gas, Erie, Pa., 1913, p. 379.

SPECIFIC GRAVITY AND BAUMÉ SCALE COMPARED.

Table 14 shows Baumé hydrometer readings from 10° to 90° B. with corresponding specific gravity, and also the corresponding weight of gasoline in pounds per United States gallon at 60° F.

TABLE 14.—*Baumé scale and specific gravity equivalents.*^a

° B.	Specific gravity.	Pounds in gallon.	° B.	Specific gravity.	Pounds in gallon.	° B.	Specific gravity.	Pounds in gallon.
10	1.000	8.33	37	0.8383	6.99	64	0.7216	6.01
11	0.9929	8.27	38	0.8333	6.94	65	0.7179	5.98
12	0.9859	8.21	39	0.8284	6.90	66	0.7143	5.96
13	0.9790	8.15	40	0.8235	6.86	67	0.7107	5.92
14	0.9722	8.10	41	0.8187	6.82	68	0.7071	5.89
15	0.9655	8.04	42	0.8140	6.78	69	0.7035	5.86
16	0.9589	7.99	43	0.8092	6.74	70	0.7000	5.83
17	0.9524	7.93	44	0.8046	6.70	71	0.6965	5.80
18	0.9459	7.88	45	0.8000	6.66	72	0.6931	5.77
19	0.9396	7.83	46	0.7955	6.62	73	0.6897	5.74
20	0.9333	7.77	47	0.7910	6.59	74	0.6863	5.71
21	0.9272	7.72	48	0.7865	6.55	75	0.6829	5.69
22	0.9211	7.67	49	0.7821	6.51	76	0.6796	5.66
23	0.9150	7.62	50	0.7778	6.48	77	0.6763	5.63
24	0.9091	7.57	51	0.7735	6.44	78	0.6731	5.60
25	0.9032	7.52	52	0.7692	6.40	79	0.6699	5.58
26	0.8974	7.47	53	0.7650	6.37	80	0.6677	5.55
27	0.8917	7.42	54	0.7609	6.33	81	0.6635	5.52
28	0.8861	7.38	55	0.7568	6.30	82	0.6604	5.50
29	0.8805	7.33	56	0.7527	6.27	83	0.6573	5.47
30	0.8750	7.29	57	0.7487	6.23	84	0.6542	5.45
31	0.8696	7.24	58	0.7447	6.20	85	0.6512	5.42
32	0.8642	7.20	59	0.7407	6.17	86	0.6482	5.40
33	0.8589	7.15	60	0.7368	6.13	87	0.6452	5.37
34	0.8537	7.11	61	0.7330	6.10	88	0.6422	5.35
35	0.8485	7.07	62	0.7292	6.07	89	0.6393	5.32
36	0.8434	7.02	63	0.7254	6.04	90	0.6364	5.30

^a U. S. Bureau of Standards, United States standard tables for petroleum oils, Circular 57, 1916, p. 5.

NOTE.—Degrees Baumé may be converted to specific gravity by adding 130 to the number of degrees Baumé and dividing the sum by 140.

CAPACITIES OF ORIFICES.

Table 15 shows the capacities of orifices, for testing small flows of natural gas, ranging from one-eighth of an inch to 1½ inches in diameter in plates one-eighth of an inch thick.

TABLE 15.—Capacities of orifices for testing flows of natural gas from small gas wells and casing-head gas from oil wells. ^a
[Temperature, 60° F.; atmospheric pressure, 14.4 pounds per square inch.]

THREE-EIGHTHS-INCH ORIFICE IN PLATE ONE-EIGHTH INCH THICK.

Pressure. Inches of water.	Capacity, in cubic feet per 24 hours, at specific gravity of—											
	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	1	1.05	1.10	1.15
0.5.....	2,270	2,180	2,100	2,030	1,970	1,910	1,850	1,810	1,760	1,720	1,680	1,640
1.0.....	3,460	3,320	3,200	3,090	3,000	2,910	2,820	2,750	2,680	2,620	2,550	2,500
1.5.....	4,310	4,140	3,990	3,860	3,730	3,620	3,520	3,430	3,350	3,280	3,190	3,110
2.0.....	4,830	4,640	4,470	4,320	4,180	4,060	3,940	3,840	3,740	3,650	3,560	3,470
2.5.....	5,190	5,000	4,830	4,680	4,540	4,420	4,300	4,190	4,080	3,980	3,890	3,800
3.0.....	5,770	5,550	5,350	5,170	5,000	4,840	4,690	4,550	4,410	4,270	4,130	4,000
3.5.....	6,450	6,200	5,980	5,780	5,600	5,430	5,280	5,130	4,970	4,820	4,670	4,530
4.0.....	7,240	6,960	6,720	6,500	6,300	6,110	5,930	5,760	5,580	5,410	5,240	5,080
4.5.....	8,150	7,850	7,600	7,360	7,140	6,940	6,750	6,560	6,370	6,180	6,000	5,820
5.0.....	9,180	8,860	8,600	8,350	8,120	7,900	7,690	7,480	7,270	7,060	6,860	6,660
5.5.....	10,330	9,990	9,720	9,450	9,200	8,960	8,730	8,500	8,270	8,040	7,810	7,580
6.0.....	11,600	11,240	10,960	10,680	10,420	10,170	9,920	9,670	9,420	9,170	8,920	8,670

ONE-HALF-INCH ORIFICE IN PLATE ONE-EIGHTH INCH THICK.

Pressure. Inches of water.	Capacity, in cubic feet per 24 hours, at specific gravity of—											
	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	1	1.05	1.10	1.15
0.5.....	4,490	4,320	4,160	4,020	3,890	3,770	3,670	3,570	3,480	3,400	3,320	3,250
1.0.....	6,260	6,010	5,790	5,600	5,440	5,280	5,110	4,970	4,850	4,730	4,620	4,520
1.5.....	7,940	7,590	7,310	7,070	6,840	6,640	6,450	6,280	6,120	5,970	5,830	5,700
2.0.....	9,140	8,780	8,460	8,170	7,910	7,680	7,460	7,260	7,080	6,910	6,750	6,600
2.5.....	10,220	9,820	9,470	9,140	8,850	8,580	8,350	8,120	7,920	7,730	7,550	7,380
3.0.....	11,150	10,720	10,330	9,990	9,660	9,370	9,110	8,860	8,640	8,430	8,240	8,060
3.5.....	12,020	11,550	11,130	10,750	10,410	10,100	9,810	9,550	9,310	9,070	8,850	8,640
4.0.....	12,800	12,290	11,850	11,440	11,060	10,750	10,450	10,170	9,910	9,670	9,450	9,240
4.5.....	13,480	12,950	12,490	12,050	11,670	11,320	11,000	10,710	10,440	10,180	9,950	9,730
5.0.....	14,130	13,570	13,080	12,640	12,230	11,870	11,530	11,230	10,940	10,680	10,430	10,200
5.5.....	14,800	14,110	13,600	13,130	12,720	12,340	11,990	11,670	11,380	11,100	10,850	10,610
6.0.....	15,510	14,620	14,080	13,610	13,170	12,780	12,420	12,090	11,780	11,500	11,250	11,010

^a Weesott, H. P., Handbook of casing-head gas, 1916, pp. 56-62.

TABLE 15.—Capacities of orifices for testing flows of natural gas from small gas wells and casing-head gas from oil wells—Continued.

THREE-FOURTHS-INCH ORIFICE IN PLATE ONE-EIGHTH INCH THICK.

Pressure.	Capacity, in cubic feet per 24 hours, at specific gravity of—													
	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	1	1.05	1.10	1.15	1.20	1.30
<i>Inches of water.</i>														
0.5	10,580	10,150	9,780	9,450	9,150	8,880	8,630	8,400	8,180	7,960	7,800	7,630	7,470	7,170
1.0	14,530	13,960	13,450	13,000	12,580	12,210	11,860	11,530	11,260	10,980	10,730	10,500	10,280	9,870
1.5	17,720	17,030	16,410	15,870	15,350	14,890	14,470	14,080	13,730	13,410	13,090	12,800	12,530	12,040
2.0	20,390	19,590	18,870	18,230	17,620	17,130	16,650	16,200	15,790	15,410	15,060	14,730	14,420	13,850
2.5	22,740	21,850	21,030	20,310	19,700	19,110	18,570	18,070	17,620	17,190	16,800	16,430	16,080	15,450
3.0	24,880	23,900	23,030	22,250	21,550	20,900	20,310	19,770	19,270	18,810	18,380	17,970	17,580	16,900
3.5	26,900	25,930	25,030	24,140	23,370	22,670	22,030	21,450	20,900	20,400	19,930	19,490	19,080	18,330
4.0	28,970	27,930	26,920	25,910	25,080	24,340	23,650	23,020	22,440	21,900	21,400	20,920	20,480	19,680
4.5	30,900	29,800	28,800	27,800	26,870	26,150	25,470	24,840	24,300	23,800	23,320	22,860	22,420	21,580
5.0	32,740	31,590	30,540	29,570	28,650	27,780	26,960	26,190	25,460	24,770	24,100	23,560	22,980	22,060
5.5	34,580	33,370	32,300	31,300	30,340	29,420	28,540	27,700	26,900	26,140	25,410	24,700	24,000	23,150
6.0	35,630	34,360	33,280	32,260	31,280	30,340	29,440	28,580	27,760	26,980	26,310	25,740	25,200	24,200

1-INCH ORIFICE IN PLATE ONE-EIGHTH INCH THICK.

1	26,440	25,440	24,500	23,600	22,920	22,220	21,600	21,020	20,520	20,010	19,560	19,120	18,720	18,000	17,320	16,750	16,200	15,720
2	37,510	36,040	34,750	33,600	32,620	31,530	30,640	29,800	29,080	28,360	27,720	27,120	26,540	25,480	24,570	23,760	22,990	22,280
3	44,440	42,640	41,000	39,500	38,120	36,800	35,560	34,380	33,260	32,180	31,140	30,140	29,160	27,800	26,570	25,380	24,240	23,160
4	52,630	50,590	48,740	47,040	45,400	43,800	42,240	40,720	39,240	37,800	36,380	35,000	33,640	31,960	30,400	28,880	27,400	26,000
5	57,880	55,630	53,610	51,780	50,160	48,610	47,080	45,580	44,100	42,640	41,200	39,780	38,380	36,760	35,280	33,760	32,280	30,760
6	63,140	60,720	58,480	56,460	54,720	53,040	51,400	49,780	48,180	46,600	45,040	43,500	41,980	40,280	38,720	37,080	35,480	33,880
7	68,110	65,470	63,060	60,910	59,040	57,210	55,400	53,600	51,800	50,020	48,240	46,480	44,740	42,960	41,370	39,660	38,000	36,380
8	73,050	70,220	67,680	65,350	63,310	61,390	59,480	57,580	55,680	53,780	51,880	49,980	48,080	46,320	44,610	42,880	41,160	39,480
9	77,080	74,060	71,280	68,800	66,560	64,440	62,320	60,200	58,080	55,960	53,840	51,720	49,600	47,480	45,360	43,240	41,120	39,000
10	82,340	79,150	76,270	73,660	71,310	69,190	67,070	64,940	62,800	60,660	58,520	56,380	54,240	52,080	49,920	47,760	45,600	43,440
11	86,680	83,320	80,300	77,540	75,120	72,810	70,490	68,170	65,840	63,500	61,160	58,820	56,480	54,120	51,760	49,400	47,040	44,680
12	90,720	87,190	84,000	81,140	78,600	76,220	74,110	72,000	70,320	68,610	67,080	65,560	64,170	62,680	61,190	59,700	58,200	56,700

Inches of mercury.

0.5	67,200	64,600	62,300	60,100	58,200	56,500	54,900	53,400	52,100	50,800	49,600	48,600	47,500	45,700	44,000	42,500	41,100	39,900
1.0	95,200	91,500	88,200	85,100	82,500	80,000	77,800	75,600	73,600	72,000	70,300	68,900	67,300	65,700	64,200	62,800	61,300	59,900
1.5	116,600	112,000	108,000	104,300	101,000	97,900	95,300	92,600	90,400	88,200	86,200	84,300	82,500	80,700	79,200	77,300	75,400	73,600
2.0	134,600	128,400	124,000	120,400	117,000	113,000	109,000	105,000	104,000	101,000	99,500	97,300	95,300	93,300	91,500	89,200	87,000	85,000
2.5	145,000	139,900	134,900	130,200	126,000	122,400	118,900	115,700	112,800	110,100	107,600	105,300	103,000	100,900	98,400	96,200	94,000	92,000
3.0	154,000	149,500	145,000	141,000	137,000	133,600	130,000	126,800	124,000	121,000	118,200	115,600	113,000	110,000	107,000	104,300	101,000	98,000
3.5	160,000	155,000	150,000	146,000	142,000	138,000	134,000	130,000	127,000	124,000	121,000	118,000	115,000	112,000	109,000	106,000	103,000	100,000
4.0	170,000	164,000	159,000	154,000	150,000	146,000	142,000	138,000	135,000	131,000	128,000	125,000	122,000	119,000	116,000	113,000	110,000	107,000
4.5	178,200	171,300	165,400	160,000	155,000	150,000	145,000	140,000	136,000	132,000	128,000	125,000	122,000	119,000	116,000	113,000	110,000	107,000
5.0	185,000	178,000	172,000	166,000	161,000	156,000	151,000	146,000	142,000	138,000	134,000	130,000	127,000	124,000	121,000	118,000	115,000	112,000
5.5	192,000	184,000	178,000	172,000	166,000	161,000	156,000	151,000	147,000	143,000	139,000	135,000	132,000	129,000	126,000	123,000	120,000	117,000
6.0	200,000	192,000	186,000	180,000	174,000	169,000	164,000	159,000	155,000	150,000	146,000	142,000	139,000	136,000	133,000	130,000	127,000	124,000
6.5	208,000	200,000	194,000	188,000	182,000	177,000	172,000	167,000	163,000	158,000	154,000	150,000	147,000	144,000	141,000	138,000	135,000	132,000
7.0	216,000	208,000	202,000	196,000	190,000	185,000	180,000	175,000	171,000	166,000	162,000	158,000	155,000	152,000	149,000	146,000	143,000	140,000
7.5	224,000	216,000	210,000	204,000	198,000	193,000	188,000	183,000	179,000	174,000	170,000	166,000	163,000	160,000	157,000	154,000	151,000	148,000
8.0	231,000	223,000	217,000	211,000	205,000	200,000	195,000	190,000	186,000	181,000	177,000	173,000	170,000	167,000	164,000	161,000	158,000	155,000
8.5	239,000	231,000	225,000	219,000	213,000	208,000	203,000	198,000	194,000	189,000	185,000	181,000	178,000	175,000	172,000	169,000	166,000	163,000
9.0	247,000	239,000	233,000	227,000	221,000	216,000	211,000	206,000	202,000	197,000	193,000	189,000	186,000	183,000	180,000	177,000	174,000	171,000
9.5	255,000	247,000	241,000	235,000	229,000	224,000	219,000	214,000	210,000	205,000	201,000	197,000	194,000	191,000	188,000	185,000	182,000	179,000
10.0	263,000	255,000	249,000	243,000	237,000	232,000	227,000	222,000	218,000	213,000	209,000	205,000	202,000	199,000	196,000	193,000	190,000	187,000
10.5	271,000	263,000	257,000	251,000	245,000	240,000	235,000	230,000	226,000	221,000	217,000	213,000	210,000	207,000	204,000	201,000	198,000	195,000
11.0	279,000	271,000	265,000	259,000	253,000	248,000	243,000	238,000	234,000	229,000	225,000	221,000	218,000	215,000	212,000	209,000	206,000	203,000
11.5	287,000	279,000	273,000	267,000	261,000	256,000	251,000	246,000	242,000	237,000	233,000	229,000	226,000	223,000	220,000	217,000	214,000	211,000
12.0	295,000	287,000	281,000	275,000	269,000	264,000	259,000	254,000	250,000	245,000	241,000	237,000	234,000	231,000	228,000	225,000	222,000	219,000

1-INCH ORIFICE IN PLATE ONE-EIGHTH INCH THICK.

Inches of water.

0.5	32,780	31,480	30,350	29,320	28,390	27,540	26,760	26,050	25,390	24,779	24,210	23,690	23,180	22,270	21,458	20,780	20,070	19,470
1.0	46,260	44,440	42,830	41,380	40,060	38,880	37,770	36,700	35,730	34,968	34,160	33,410	32,710	31,420	30,280	29,250	28,320	27,480
1.5	56,900	54,380	52,410	50,630	49,020	47,560	46,210	44,980	43,850	42,760	41,810	40,890	40,030	38,460	37,050	35,800	34,670	33,630
2.0	64,840	62,300	60,040	58,000	56,160	54,480	52,940	51,530	50,230	49,020	47,890	46,840	45,850	44,050	42,450	41,010	39,710	38,520
2.5	72,400	69,570	67,040	64,700	62,500	60,830	59,120	57,540	56,060	54,735	53,480	52,300	51,200	49,190	47,400	45,800	44,340	43,020
3.0	77,980	74,920	72,200	69,750	67,540	65,520	63,670	61,970	60,410	58,950	57,600	56,330	55,150	52,980	51,050	49,300	47,760	46,330
3.5	84,480	81,180	78,220	75,570	73,170	70,980	68,980	67,140	65,450	63,870	62,400	61,030	59,750	57,400	55,310	53,440	51,740	50,200
4.0	91,400	87,810	84,620	81,750	79,150	76,790	74,620	72,630	70,800	69,090	67,500	66,020	64,630	62,090	59,840	57,810	55,970	54,300
4.5	97,810	93,980	90,500	87,490	84,710	82,180	79,860	77,730	75,770	73,940	72,240	70,650	69,170	66,450	64,040	61,860	59,900	58,110
5.0	103,200	99,210	95,610	92,370	89,430	86,700	84,310	82,070	80,000	78,070	76,280	74,600	73,030	70,160	67,610	65,320	63,240	61,360
5.5	107,230	103,020	99,280	95,910	92,870	90,090	87,560	85,210	83,060	81,060	79,194	77,450	75,820	72,850	70,200	67,820	65,660	63,700

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OIL-STORAGE TANKS AND RESERVOIRS

WITH A BRIEF DISCUSSION OF LOSSES OF OIL
IN STORAGE AND METHODS OF PREVENTION

BY

C. P. BOWIE



WASHINGTON
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1918

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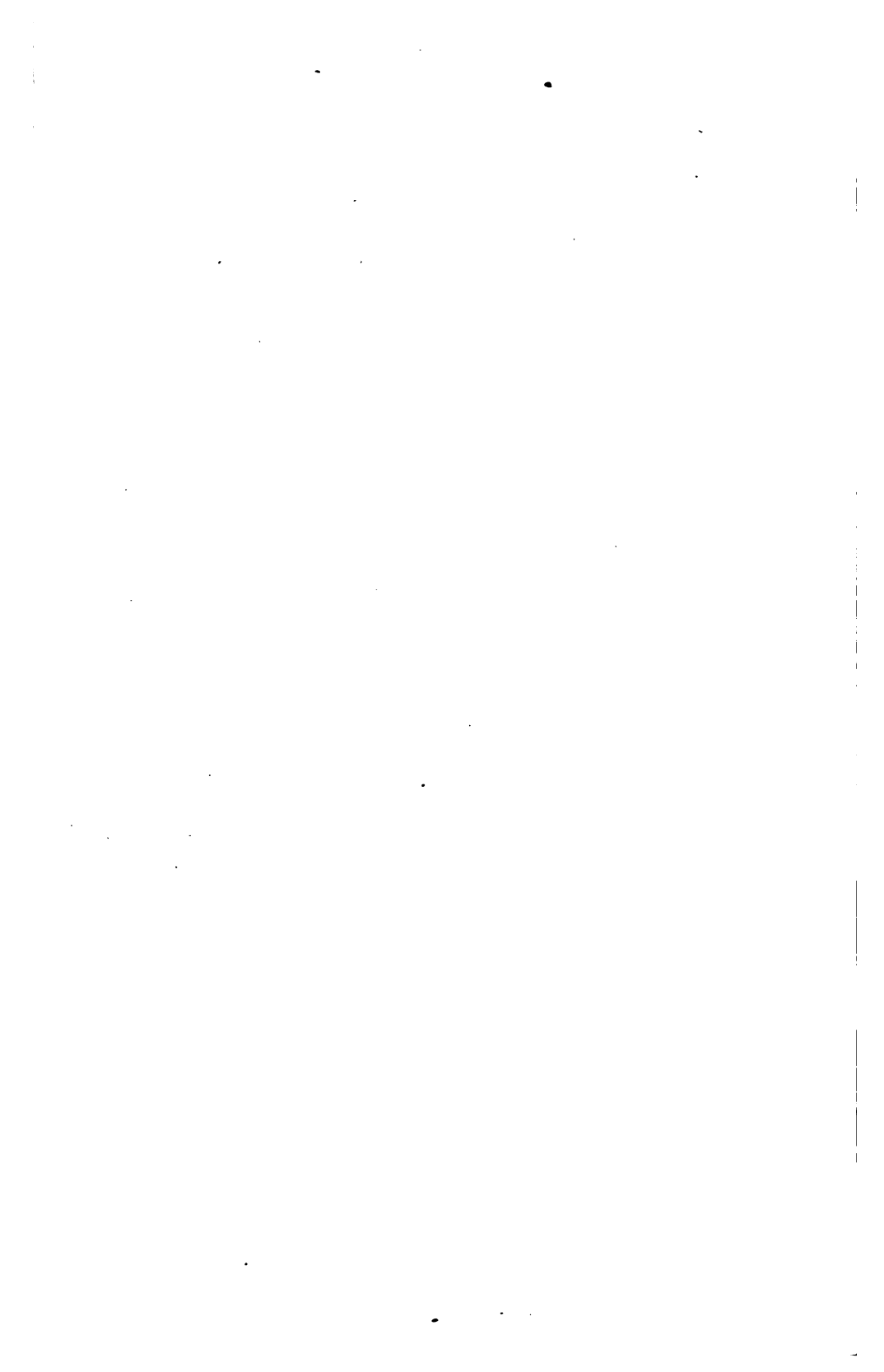
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OIL-STORAGE TANKS AND RESERVOIRS, WITH A BRIEF DISCUSSION OF LOSSES OF OIL IN STORAGE AND METHODS OF PREVENTION.

By C. P. BOWIE.

INTRODUCTION.

The Bureau of Mines has been conducting investigations with the view of determining the types of containers best adapted to the storage of oil. These investigations have shown that tanks composed wholly of steel give the best results. Where larger containers than it is feasible to build with steel are desired, concrete-lined reservoirs can be recommended for some grades of oil. Practically all such containers in use at present have wooden roofs and this type of construction is here described, although it is the belief of the writer that concrete roofs would be far more satisfactory in every way, and that the difference in cost between a concrete and a wooden roof would, as a rule, in a few years' time, be offset by a saving of oil and in cost of repairs and renewals.

TANK FARMS.

Storage facilities, whether steel tanks or reservoirs, are grouped together in what are known as "storage farms," some of which in the United States already have capacities in excess of 24,000,000 barrels. The ideal site for a farm is on ground that is comparatively level. Tanks, which are usually of 37,000 to 55,000 barrel capacity, are placed about 500 feet center to center, making the distance shell to shell about 400 feet. Each tank is then surrounded by a levee of sufficient height to hold the entire content of the tank, as shown on Plate I, A. In many instances these levees are circular and are themselves inclosed by a system of rectangular levees, built equidistantly between tanks, and dividing the whole farm into a system of checkerboard squares, the tanks being at the centers of the squares. Should any one tank catch fire it is thus isolated from its neighbors, and even though it may burn until its entire contents are consumed, if the levees are properly constructed it will do so without undue menace to the other tanks. As regards large reservoirs of 500,000 to 1,000,000 barrel

capacity, it is of course not practical to make the empounding area of a surrounding levee of sufficient size to hold the entire contents of the reservoir. Nevertheless, levees between reservoirs are advisable, and it is the practice to provide them. Levees are to be discussed more fully in a subsequent publication on fire protection to be issued by the Bureau of Mines.

SIZES OF STEEL TANKS.

Steel tanks for the storage of oil are manufactured in various sizes up to 55,000-barrel capacity. These have a diameter of 114 feet 6 inches and are 30 feet high. The usual size is the 55,000-barrel tank, although the Standard Oil Co., especially, is using great numbers of 37,000-barrel tanks. Tanks may be erected by contract or by the owners. However, for various reasons, the contract method is generally preferable. Under this method the company furnishes the grades on which the tanks are placed, and transportation of men and materials from the nearest railroad station; the contractors furnish the material, the railroad transportation, and all labor for erection.

TANK GRADES.

As to tank grades, it is well to note in passing that too much care can not be exercised in their preparation. They should be either all in fill or all in excavation and carefully graded to a true level surface. Plate I, *B*, shows the method of setting grade stakes. A tank built partly on filled ground and partly on excavated ground is in constant danger of being disrupted at the point where the foundation goes from cut to fill, as the filled part of the foundation will settle, whereas the part in cut ground probably will not, or at least not to so great a degree. Where it is necessary to build up a grade, the best policy is to fill the entire area to approximately the same depth, so as to insure as uniform settling as possible. It is good practice, also, unless the length of haul is excessive, to use the Fresno type of grader and to distribute the dirt in thin layers, allowing the stock to pass back and forth over the loose material as often as feasible. Puddling the grade in filled ground is also good practice.

As the bottom of the tank is composed of relatively thin plates, every precaution should be taken to prevent its deterioration from the corrosive action of alkaline salts contained in the soil upon which it rests, and also from similar chemical action by reason of water leaking through an imperfect seam and forming a puddle beneath the plates.

To eliminate as far as possible the detrimental effect of soil corrosion, several inches of oil sand is usually placed on the surface of the completed grade, or if this is impracticable, the completed surface is oiled, and the oil worked in 3 to 4 inches by rakes. The tank bot-



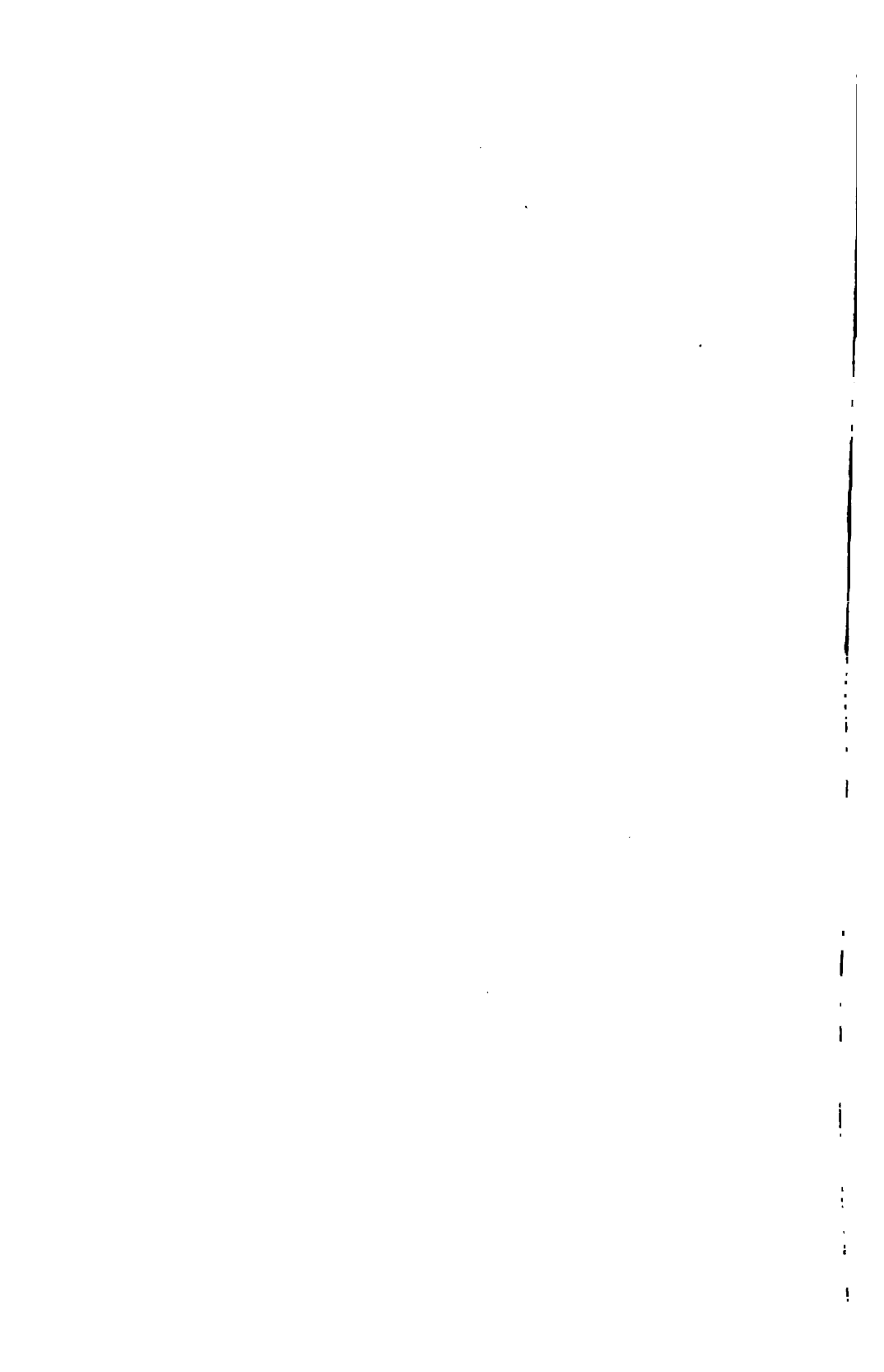
A. PART OF A TANK FARM UNDER CONSTRUCTION.



B. METHOD OF SETTING GRADE STAKES FOR FINISHING TANK GRADE TO TRUE LEVEL.



C. TANK BOTTOM IN COURSE OF CONSTRUCTION.



tom is thoroughly coated with a good quality of asphaltic or other rust-resisting paint before being lowered onto the grade. Plate I, C, shows a tank bottom in course of construction.

TANK SPECIFICATIONS.

Perhaps no better description of a steel tank can be given than that furnished by a recital of the specifications covering its erection and the material of which it is composed. Following are such specifications for a tank of 55,000-barrel capacity, of steel construction throughout, and of a type known to the trade as "gas-tight." This capacity of tank is considered to be the largest practicable for fabrication and construction in the field, and the type of steel tank best adapted to the storage of petroleum products so far as regards fire hazards and losses by seepage and evaporation.

SPECIFICATIONS FOR 55,000-BARREL ^a STEEL TANK WITH STEEL ROOF.

The _____, in itself or by its duly authorized representative, shall be referred to in these specifications as the "Company."

The firm undertaking to furnish and erect the tank herein described, in itself or by its duly authorized representative, shall be referred to in these specifications as the "Contractor."

At all times during the progress of the fabrication of the tank material or erection of the tank, the Contractor shall designate some person as his representative, to whom instructions may be given by a duly authorized representative of the Company.

(1) *Location*.—Tank to be erected upon foundation prepared by the Company.

(2) *Freight and hauling*.—The Contractor shall deliver all tank material, tools, and appliances f. o. b. cars nearest railroad station. The Company shall haul all tank material, tools, and appliances necessary for the construction of the tank from the railroad station, and shall deliver same within 100 feet of the tank site, and on completion of the work shall return tools and appliances to the railroad station.

(3) *Drawings*.—The following drawings form an integral part of and are to be used in conjunction with these specifications: Plates II, III, IV, V, VI, VII, and VIII.

(4) *Dimensions*.—Diameter, 114 feet 6 inches, average inside measurement; height, 30 feet.

(5) *Material*.—All material for the tank shall be of steel, complying with Standard Specifications for Structural Steel of the American Society for Testing Materials (copy of which is hereto attached). Contractor to furnish a certificate from an approved firm of testing engineers covering all materials used, but such certificate shall not act to prevent Company exercising the right to reject undergaged plates or defective material wherever it may be found.

Tank to be composed of 6 rings of equal height, as shown on Plate II. Plates to be of uniform size with minimum dimensions, as hereinafter designated.

All plates shall be ordered to gage, permissible variations to be in accord with specifications for structural steel above referred to.

(6) *Punching and riveting, etc.*—Plates and angles for the shell of the tank must be rolled to proper curvature.

Plates and angles must be punched from the sides that are to be in contact, and the punching must be so accurate that the holes will match within 10 per cent of their diameter when plates are assembled. Holes for hot rivets shall be punched

^a 42-gallon barrels.

not more than one-sixteenth of an inch larger in diameter than the rivets that are to fill them.

Riveting shall be done with pneumatic tools, an air pressure of approximately 90 pounds per square inch at the receiver being used. Rivets must conform with the specifications in diameter, length, pitch, and marginal distance. Should any burned, deformed, or loose rivets be found in the work, they are to be cut out and replaced. No calking of rivets will be allowed. Riveting of the bottom sheets shall be done from the inside; all other riveting, including riveting of the bottom to the bottom angle, and of the roof, shall be done from the outside. All rivets one-half inch in diameter or larger shall be driven hot.

(7) *Calking*.—All edges to be calked shall be beveled by planing. All seams must be thoroughly calked with a round-nosed pneumatic calking tool. The shell of the tank shall be formed by ascending inside courses calked on the outside. Bottom plates to be calked on the inside except at angle iron, where they are to be calked on the outside, and both legs of angle iron shall be calked inside. Angle irons to be butt calked at joints.

All roof plates to be calked from the outside of tank, this to include also calking at top angle iron.

All castings, nozzles, flanges, and manheads riveted to the tank must be calked thoroughly inside and outside.

(8) *Testing the bottom*.—Upon completion of the bottom and the first ring of the shell, and before the bottom has been lowered to the ground, the bottom shall be covered with water to a depth of not less than 5 inches, and all leaks that develop shall be made tight to the satisfaction of the Company or its duly authorized representative before any lowering is done. Necessary water for the testing shall be furnished by the Company for one test only. Should additional tests be made, water will be charged to the contractor at cost.

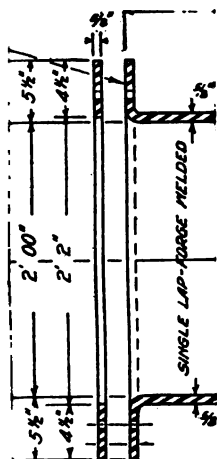
(9) *Thickness of metal, spacing of rivets, etc.*—The thickness of metal, the spacing of rivets, and the like, shall be as set forth in the following table:

Thickness of metal, spacing of rivets, etc., prescribed for tank covered by these specifications.

Part.	Thick- ness.	Weight per square foot.	Horizontal rivet- ing—all single rows.		Vertical riveting.			
			Diam- eter of rivets.	Pitch.	Rows.	Diam- eter of rivets.	Pitch.	Distance between rows, center to center.
	<i>Inches.</i>	<i>Pounds.</i>	<i>Inches.</i>	<i>Inches.</i>		<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>
Bottom sketch plates.....	$\frac{1}{4}$	12.75		$\frac{11}{16}$				
Bottom rectangular plates....	$\frac{1}{4}$	10.20		$\frac{11}{16}$				
First ring.....	$\frac{1}{4}$	22.95	1	$\frac{1}{2}$	Triple..		$\frac{3}{4}$	3
Second ring.....	$\frac{1}{4}$	20.40		$\frac{1}{2}$	do....		$\frac{3}{4}$	3
Third ring.....	$\frac{1}{4}$	18.68		$\frac{1}{2}$	Double..		$\frac{3}{4}$	3
Fourth ring.....	$\frac{1}{4}$	12.75		$\frac{1}{2}$	do....		$\frac{3}{4}$	$\frac{11}{16}$
Fifth ring.....	$\frac{1}{4}$	10.20		$\frac{1}{2}$	do....		$\frac{3}{4}$	$\frac{11}{16}$
Sixth ring.....	$\frac{1}{4}$	10.20		3	do....		$\frac{3}{4}$	$\frac{11}{16}$
Roof plates.....	$\frac{1}{4}$	7.65		$1\frac{1}{2}$				

(10) *Size of plates and angles*.—Plates for shell shall be 60 by 180 inches center to center of rivet laps (24 plates per ring). Bottom and top rectangular plates shall be 60 by 180 inches center to center of rivet laps. Bottom angle irons connecting the bottom and the shell shall be 4 by 4 inches by $\frac{3}{4}$ inch. Top angle iron connecting the roof with the shell shall be 3 by 3 inches by $\frac{3}{4}$ inch.

(11) *Angle shoes*.—Shoes uniting ends of angles shall be made of $\frac{3}{4}$ -inch 16-pound el, and shall be not less than 12 inches in length with the ends drawn to a thin edge.



ETS ON 2' 5" R.C.

S ON 2' 8 1/2" R.C.

MANHOL.

2 WANTED - COA

Shoes must be set between steel angles, shell and bottom of tank, and must be of sufficient width to be properly calked outside the line of the steel angles.

(12) *Shell*.—The shell shall be composed of 6 courses, as shown on Plate II, each course to be a true circle and to be free from flaws and buckles. The first two courses, counting from the bottom upward, are to have the vertical seams triple riveted. The third, fourth, and fifth courses are to have the vertical seams double riveted. All horizontal seams are to be single riveted.

(13) *Roof*.—Roof to be composed of $\frac{1}{8}$ -inch steel plates weighing 7.65 pounds per square foot, and to rest on steel roof supports as shown on Plate III. The roof, however, shall not be riveted to roof supports at any point. When complete the roof must be "gas tight," and shall show no leaks when tested with an air pressure equal to the weight of the roof.

(14) *Roof supports*.—Roof supports shall be constructed of steel shapes as shown on Plate III. Size and fabrication to conform to those shown, and workmanship to be approved by the Company.

(15) *Manholes*.—Two manholes shall be placed in the first course of tank, as designated by the Company in the field. Each manhole shall be 20 inches deep, and shall be made of steel with welded seam, weighing not less than 21 pounds per square foot. Neck of flange must be covered to suit radius of tank shell. The manhole shall be fitted with steel cover plate five-eighths inch thick, faced and punched to suit holes in flange, and bolted to flange with 24 $\frac{1}{2}$ -inch square-head bolts and hexagon nuts. The manhole shall be riveted to tank shell with $\frac{1}{2}$ -inch rivets, as shown on Plate II.

(16) *Pipe flanges, nozzles, etc.*—The tank shall be furnished with the following pressed-steel flanges secured to the shell with $\frac{1}{2}$ -inch diameter rivets. Position to be designated in field by the Company. One pair of flanges to be threaded for 8-inch pipe for drawing off water. One pair of flanges to be threaded for 8-inch pipe for oil-inlet pipe. Bottom of tank to be fitted with one single flange threaded for 8-inch pipe, secured to bottom of tank with $\frac{1}{2}$ -inch rivets, location to be designated in the field by the Company. Roof of tank to be fitted with two 8-inch and one 4-inch pressed-steel flanges located in field by the Company, also with manholes and gage hatch, as shown in detail on Plate III.

Tank to be fitted with one combined swing pipe and suction nozzle, as shown in detail on Plate II. Nozzle to be made of single-lap forge-welded steel plate $\frac{1}{2}$ inch thick, and to be secured to shell of tank in position located in the field by the Company, with a double row of $\frac{1}{2}$ -inch rivets, as shown on drawing. Swing pipe and suction end of nozzle to be fitted with cast-steel flange, as shown.

(17) *Swing pipe*.—Contractor shall supply and install swing pipe as shown in detail on Plate IV. Swing pipe to be delivered on the job so that it may be placed (but not installed) inside of the tank shell as soon as the bottom is tested and lowered. Contractor will not be permitted to lift the swing pipe over the shell of the tank after more than the first ring of the tank is in position.

(18) *Double-swivel joint for swing pipe*.—Contractor shall supply and install to the satisfaction of the Company a double-swivel elbow joint for connecting the swing pipe to the swing-pipe nozzle. Details for this swivel joint are shown on Plate V. Construction of joint must follow closely details as per drawing.

(19) *Stairway*.—The Contractor shall furnish and install a stairway anchored to the shell of the tank and running from the ground to the top of the tank, as shown on Plate VI. This stairway shall be equipped with door covered with No. 12 wire screen, $\frac{1}{4}$ -inch mesh, as shown on Plate VI.

(20) *Explosion hatches*.—The tank shall be equipped with eight explosion hatches to be located on roof of tank in field as designated by the Company. Details of explosion hatches are shown on Plate VII. These explosion hatches are to be furnished by Contractor and must conform closely to drawing. Brass rods must be true and

smoothly turned, and must be accurately fitted in babbitted bearings, as shown, in order that aluminum cover of hatch will rise without binding.

(21) *Cable guides and stuffing box.*—Tank shall be provided with cable guides and stuffing box for cable, as shown in detail on Plate VIII. One hundred feet of $\frac{1}{4}$ -inch diameter 6-strand 19-wire plow-steel galvanized-wire cable shall be furnished by Contractor. Sheave wheels for cable must be accurately centered and supports securely riveted to tank shell and calked inside and outside of tank.

(22) *Swing-pipe winch.*—Swing-pipe winch shall be furnished by Contractor as per detail shown on Plate VIII, and shall be placed in position by Contractor where designated by the Company.

(23) *Painting.*—The outside of the tank, including the top, shall be painted with one coat of asphaltic, graphite, or other paint approved by the Company, to be spread on with brush and to thoroughly cover the metal. The bottom of the tank shall be painted with three coats of the same paint, at least 6 hours being allowed for each successive coat to dry.

(24) *Inspection.*—All material and workmanship shall be subject at all times to the inspection of the Company or its duly authorized representative, and any defective material, whether discovered before or after it has been used in the work, shall be replaced in the construction by the Contractor at his own expense. Contractor shall also furnish transportation from railroad to tank site for such new material.

(25) *Final test.*—Upon the completion of the tank, and before it is inspected, it may be filled with oil or water at the option and expense of the Company, and any leaks that develop shall be made tight to the satisfaction of the Company by the Contractor at his own expense.

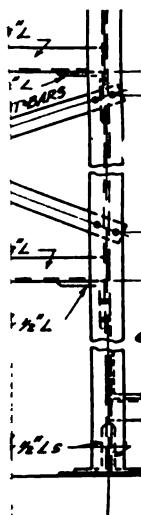
(26) *Boarding of work crew.*—The Contractor shall provide board, lodging, and transportation for his men at all times. Commissary water will be furnished by the Company. Purifying of same, where necessary, to be done by the Contractor. No intoxicating liquors shall be permitted on the premises.

(27) *Workmanship.*—The work throughout shall be done in a first-class workmanlike manner, and only men competent in their line shall be employed about the work. Upon demand of the Company, or its duly authorized representative, any workman who in the judgment of the Company is found to be incompetent, careless, or intemperate shall be dismissed.

(28) *Extra work.*—These plans and specifications are intended to describe a complete oil-tight and gas-tight tank. Any work and material necessary to produce such a tank, although not mentioned in the specifications or shown on the plans, shall be supplied by the Contractor without extra cost to the Company. The Company will not pay for extra work unless it has been executed on a written order by the Company, or its duly authorized representative.

(29) *Rubbish.*—On completion of the work all useless material used in the construction shall be cleared away from inside and outside the tank, and shall be removed to such a point upon the premises as may be designated by the Company.

(30) *Camp sanitation.*—The Contractor shall at all times maintain his boarding house, sleeping quarters, and all other appurtenant facilities in a sanitary condition to the satisfaction of the Company.



10-BARREL

not more than one-sixteenth of an inch larger in diameter than the rivets that will fill them.

Riveting shall be done with pneumatic tools, an air pressure of approximately pounds per square inch at the receiver being used. Rivets must conform with specifications in diameter, length, pitch, and marginal distance. Should any be deformed, or loose rivets be found in the work, they are to be cut out and replaced. No calking of rivets will be allowed. Riveting of the bottom sheets shall be done from the inside; all other riveting, including riveting of the bottom to the bottom and of the roof, shall be done from the outside. All rivets one-half inch in diameter or larger shall be driven hot.

(7) *Calking*.—All edges to be calked shall be beveled by planing. All seams shall be thoroughly calked with a round-nosed pneumatic calking tool. The shell of the tank shall be formed by ascending inside courses calked on the outside. Bottom plates to be calked on the inside except at angle iron, where they are to be calked on the outside, and both legs of angle iron shall be calked inside. Angle irons shall be butt calked at joints.

All roof plates to be calked from the outside of tank, this to include also calking at top angle iron.

All castings, nozzles, flanges, and manheads riveted to the tank must be calked thoroughly inside and outside.

(8) *Testing the bottom*.—Upon completion of the bottom and the first ring of the tank and before the bottom has been lowered to the ground, the bottom shall be covered with water to a depth of not less than 5 inches, and all leaks that develop shall be made tight to the satisfaction of the Company or its duly authorized representative before any lowering is done. Necessary water for the testing shall be furnished by the Company for one test only. Should additional tests be made, water will be charged to the contractor at cost.

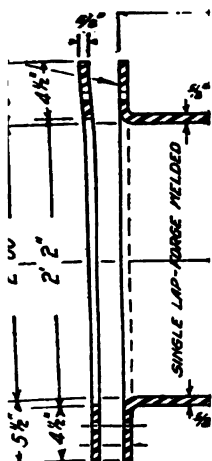
(9) *Thickness of metal, spacing of rivets, etc.*—The thickness of metal, the spacing of rivets, and the like, shall be as set forth in the following table:

Thickness of metal, spacing of rivets, etc., prescribed for tank covered by these specifications

Part.	Thick- ness.	Weight per square foot.	Horizontal rivet- ing—all single rows.		Vertical riveting.			
			Diam- eter of rivets.	Pitch.	Rows.	Diam- eter of rivets.	Pitch.	Distance between rivets center to center
	Inches.	Pounds.	Inches.	Inches.		Inches.	Inches.	Inches.
Bottom sketoh plates.....	$\frac{1}{2}$	12.75	$\frac{1}{2}$	1 $\frac{1}{2}$				
Bottom rectangular plates.....	$\frac{1}{2}$	10.20	$\frac{1}{2}$	1 $\frac{1}{2}$				
First ring.....	$\frac{1}{2}$	22.95	1	2 $\frac{1}{2}$	Triple..			3
Second ring.....	$\frac{1}{2}$	20.40	$\frac{1}{2}$	2 $\frac{1}{2}$	do.			3
Third ring.....	$\frac{1}{2}$	16.58	$\frac{1}{2}$	2 $\frac{1}{2}$	Double..			2 $\frac{1}{2}$
Fourth ring.....	$\frac{1}{2}$	12.75	$\frac{1}{2}$	2 $\frac{1}{2}$	do.			2 $\frac{1}{2}$
Fifth ring.....	$\frac{1}{2}$	10.20	$\frac{1}{2}$	2	do.			2 $\frac{1}{2}$
Sixth ring.....	$\frac{1}{2}$	10.20	$\frac{1}{2}$	2	do.			2 $\frac{1}{2}$
Roof plates.....	$\frac{1}{2}$	7.65	$\frac{1}{2}$	1 $\frac{1}{2}$				

(10) *Size of plates and angles*.—Plates for shell shall be 60 by 180 inches center to center of rivet laps (24 plates per ring). Bottom and top rectangular plates shall be 60 by 180 inches center to center of rivet laps. Bottom angle irons connecting the bottom and the shell shall be 4 by 4 inches by $\frac{1}{2}$ inch. Top angle iron connecting the roof with the shell shall be 3 by 3 inches by $\frac{1}{2}$ inch.

(11) *Angle shoes*.—Shoes uniting ends of angles shall be made of $\frac{3}{4}$ -inch 16-pound steel, and shall be not less than 12 inches in length with the ends drawn to a thin edge.



TS ON 2' 5" R.C.
ON 2' 8" R.C.

MANHOL.

2 WANTED - COM

AMERICAN SOCIETY FOR TESTING MATERIALS.

Philadelphia, Pa., U. S. A.

Affiliated with the
International Association for Testing Materials.STANDARD SPECIFICATIONS
FOR
STRUCTURAL STEEL FOR BUILDINGS.

Serial designation: A 9-16.

Adopted 1901; revised 1909, 1913, 1914, 1916.

I. MANUFACTURE.

Process.

1. (a) Structural steel, except as noted in paragraph b, may be made by the Bessemer or the open-hearth process.
- (b) Rivet steel, and steel for plates or angles over $\frac{3}{4}$ inch in thickness which are to be punched, shall be made by the open-hearth process.

II. CHEMICAL PROPERTIES AND TESTS.

Chemical composition.

2. The steel shall conform to the following requirements as to chemical composition:

	Structural steel.	Rivet steel.
Phosphorus { Bessemer.....	Not over 0.10 per cent.	
Open-hearth.....	Not over 0.06 per cent.	Not over 0.06 per cent.
Sulphur.....		Not over 0.045 per cent.

Ladle analyses.

3. An analysis of each melt of steel shall be made by the manufacturer to determine the percentages of carbon, manganese, phosphorus, and sulphur. This analysis shall be made from a test ingot taken during the pouring of the melt. The chemical composition thus determined shall be reported to the purchaser or his representative, and shall conform to the requirements specified in section 2.

Check analyses.

4. Analyses may be made by the purchaser from finished material representing each melt. The phosphorus and sulphur content thus determined shall not exceed that specified in section 2 by more than 25 per cent.

III. PHYSICAL PROPERTIES AND TESTS.

Tension tests.

5. (a) The material shall conform to the following requirements as to tensile properties:

Properties considered.	Structural steel.	Rivet steel.
Tensile strength, pounds per square inch.....	55,000 to 65,000.....	46,000 to 56,000.
Yield point, minimum, pounds per square inch.	0.5 tensile strength....	0.5 tensile strength.
Elongation in 8 inches, minimum, per cent....	$\frac{1,400,000}{\text{Tensile strength}}^a$	$\frac{1,400,000}{\text{Tensile strength}}$
Elongation in 2 inches, minimum, per cent....	22.....	.....

^a See section 6.

- (b) The yield point shall be determined by the drop of the beam of the testing machine.

Modifications in elongation.

6. (a) For structural steel over $\frac{1}{4}$ inch in thickness, a deduction of 1 from the percentage of elongation in 8 inches specified in section 5, a, shall be made for each increase of $\frac{1}{4}$ inch in thickness above $\frac{1}{4}$ inch, to a minimum of 18 per cent.

(b) For structural steel under $\frac{1}{4}$ inch in thickness, a deduction of 2.5 from the percentage of elongation in 8 inches specified in section 5, a, shall be made for each decrease of $\frac{1}{4}$ inch in thickness below $\frac{1}{4}$ inch.

Bend tests.

7. (a) The test specimen for plates, shapes, and bars, except as specified in paragraphs b and c, shall bend cold through 180 degrees without cracking on the outside of the bent portion, as follows: For material $\frac{1}{4}$ inch or under in thickness, flat on itself; for material over $\frac{1}{4}$ inch to and including $1\frac{1}{2}$ inches in thickness, around a pin the diameter of which is equal to the thickness of the specimen; and for material over $1\frac{1}{2}$ inches in thickness, around a pin the diameter of which is equal to twice the thickness of the specimen.

(b) The test specimen for pins, rollers, and other bars, when prepared as specified in section 8, e, shall bend cold through 180 degrees around a 1-inch pin without cracking on the outside of the bent portion.

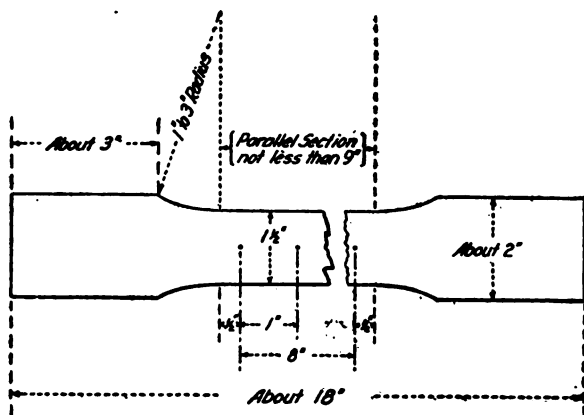


FIGURE 1.—Form and dimensions of test specimen for tension and bending tests of plates, shapes, and bars.

(c) The test specimen for rivet steel shall bend cold through 180 degrees flat on itself without cracking on the outside of the bent portion.

Test specimens.

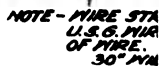
8. (a) Specimens for tension and bending tests shall be taken from rolled steel in the condition in which it comes from the rolls, except as specified in paragraph b.

(b) Specimens for tension and bending tests of pins and rollers shall be taken from the finished bars, after annealing when annealing is specified.

(c) Specimens for tension and bending tests of plates, shapes, and bars, except as specified in paragraphs d, e, and f, shall be of the full thickness of material as rolled; and may be machined to the form and dimensions shown in figure 1, or with both edges parallel.

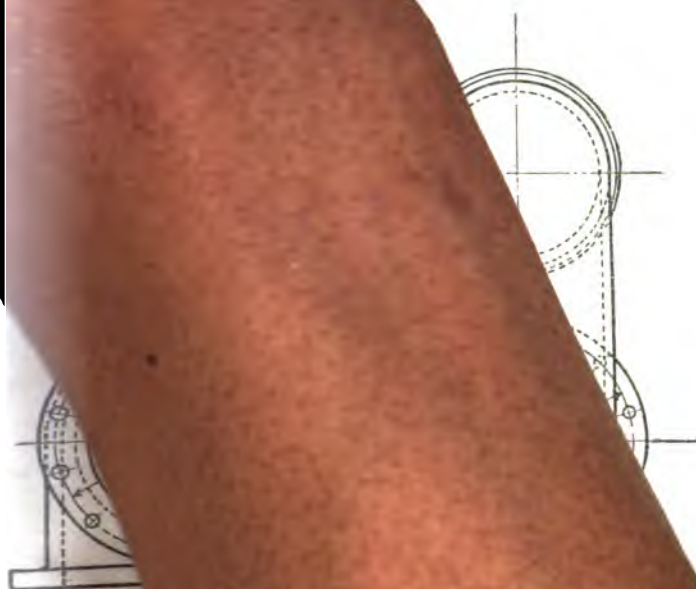
(d) Specimens for tension and bending tests of plates over $1\frac{1}{2}$ inches in thickness may be machined to a thickness or diameter of at least $\frac{1}{4}$ inch for a length of at least 9 inches.

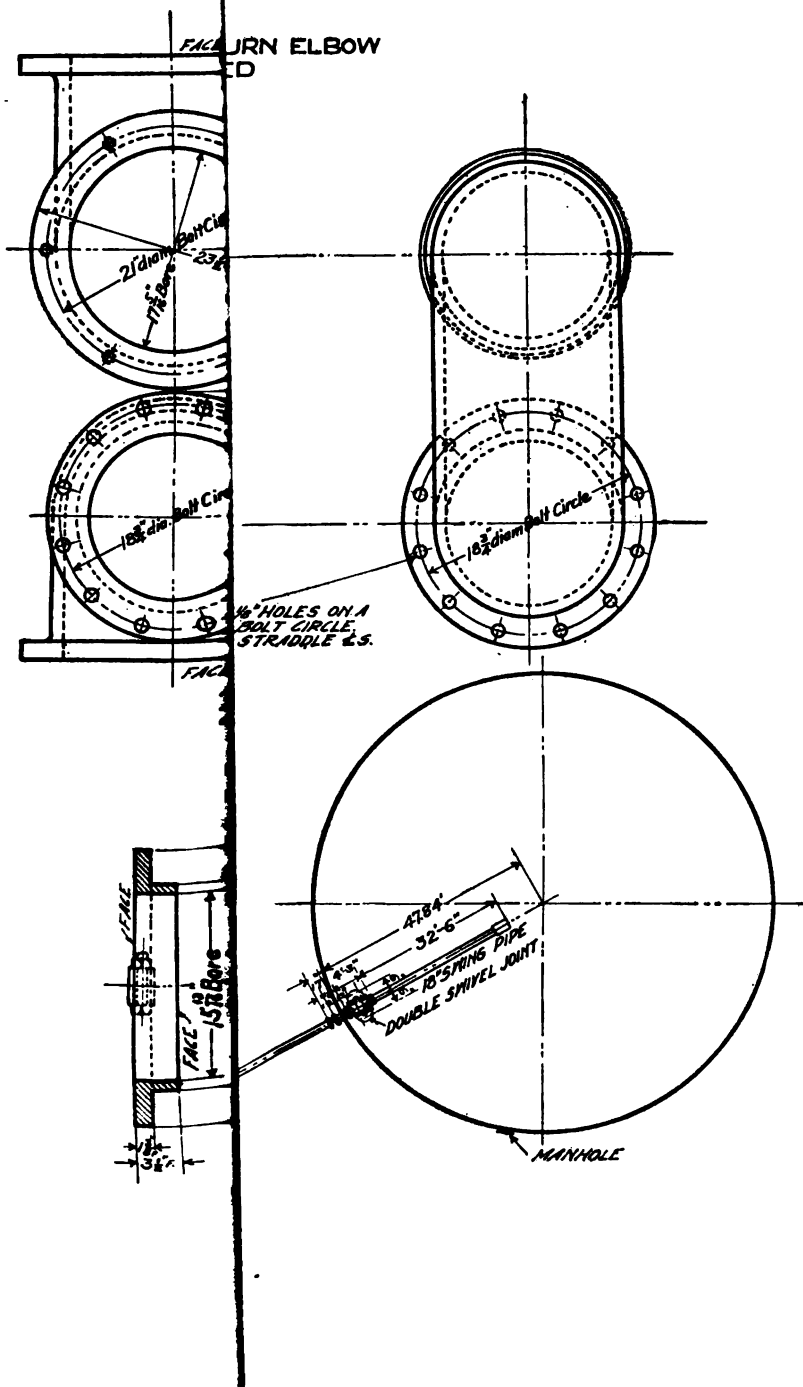
(e) Specimens for tension tests of pins, rollers, and bars more than $1\frac{1}{2}$ inches in thickness or diameter may conform to the dimensions shown in figure 2. In this case, the ends shall be of a form to fit the holders of the testing machine in such a way that the



4 SWING PIPE.







load shall be axial. Bend test specimens may be 1 by $\frac{1}{2}$ inch in section. The axis of the specimen shall be located at any point midway between the center and surface and shall be parallel to the axis of the bar.

(f) Specimens for tension and bending tests of rivet steel shall be of the full-size section of bars as rolled.

Number of tests.

9. (a) One tension and one bending test shall be made of material from each melt; except that if material from one melt differs $\frac{1}{8}$ inch or more in thickness, one tension and one bending test shall be made from both the thickest and the thinnest material rolled.

(b) If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted.

(c) If the percentage of elongation of any tension-test specimen is less than that specified in section 5, a, and any part of the fracture is more than $\frac{1}{4}$ inch from the center of the gage length of a 2-inch specimen or is outside the middle third of the gage length of an 8-inch specimen, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

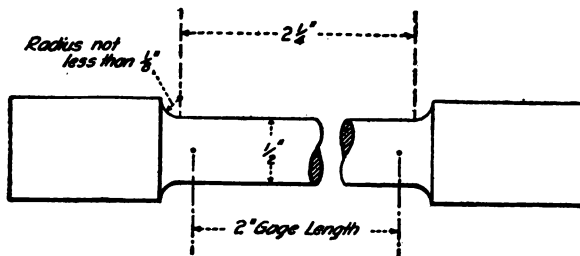


FIGURE 2.—Form and dimensions of test specimen for tension tests of pins, rollers, and bars more than $\frac{1}{2}$ inches thick.

IV. PERMISSIBLE VARIATIONS IN WEIGHT AND THICKNESS.

Permissible variations.

10. The cross section or weight of each piece of steel shall not vary more than 2.5 per cent from that specified; except in the case of sheared plates, which shall be covered by the following permissible variations. One cubic inch of rolled steel is assumed to weigh 0.2833 pound.

(a) When ordered to weight per square foot: The weight of each lot^a in each shipment shall not vary from the weight ordered more than the amount given in Table 1.

(b) When ordered to thickness: The thickness of each plate shall not vary more than 0.01 inch under that ordered.

The overweight of each lot^b in each shipment shall not exceed the amount given in Table 2.

^a The term "lot" applied to Table 1 means all of the plates of each group width and group weight.

^b The term "lot" applied to Table 2 means all of the plates of each group width and group thickness.

OIL-STORAGE TANKS AND RESERVOIRS.

Permissible variations in average weights per square foot of plates for widths given.
(Expressed in percentages of ordered weights.)

Ordered weight.		Under 48 inches.		48 to 60 inches, exclusive.		60 to 72 inches, exclusive.		72 to 84 inches, exclusive.		84 to 96 inches, exclusive.		96 to 108 inches, exclusive.		108 to 120 inches, exclusive.		120 to 132 inches, exclusive.		132 inches or over.		Ordered weight.
Pounds per square foot.		Under.	Over.	Under.	Over.	Under.	Over.	Under.	Over.	Under.	Over.	Under.	Over.	Under.	Over.	Under.	Over.	Under.	Over.	
Under 5.....	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	Under 5.
5 to 7.5, exclusive.	4.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	5 to 7.5, exclusive.
7.5 to 10, exclusive.	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	7.5 to 10, exclusive.
10 to 12.5, exclusive.	3.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	10 to 12.5, exclusive.
12.5 to 15, exclusive.	3	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	12.5 to 15, exclusive.
15 to 17.5, exclusive.	2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	15 to 17.5, exclusive.
17.5 to 20, exclusive.	2	2	2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	17.5 to 20, exclusive.
20 to 25, exclusive.	2	2	2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	20 to 25, exclusive.
25 to 30, exclusive.	2	2	2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	25 to 30, exclusive.
30 to 40, exclusive.	2	2	2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	30 to 40, exclusive.
40 or over.....	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	40 or over.

NOTE.—The weight per square foot of individual plates shall not vary from the ordered weight by more than 1½ times the amount given in this table.

TABLE 2.—Permissible *net* weights of plates ordered to thickness.

Ordered thickness.	Permissible excess in average weights per square foot of plates for widths given. (Expressed in percentages of nominal weight.)								Ordered thickness.
	Under 48 inches.	48 to 60 inches, exclusive.	60 to 72 inches, exclusive.	72 to 84 inches, exclusive.	84 to 96 inches, exclusive.	96 to 108 inches, exclusive.	108 to 120 inches, exclusive.	120 to 132 inches, exclusive.	132 inches or over.
<i>Inches.</i>									
Under 1.	9	10	12	14					Under 1.
1 to 1/4, exclusive.	8	9	10	12					1 to 1/4, exclusive.
1/4 to 1/2, exclusive.	7	8	9	10					1/4 to 1/2, exclusive.
1/2 to 3/4, exclusive.	6	7	8	9	12	12	14	16	1/2 to 3/4, exclusive.
3/4 to 1, exclusive.	5	6	7	8	10	10	12	14	3/4 to 1, exclusive.
1 to 1 1/4, exclusive.	4.5	5	6	7	9	9	10	12	1 to 1 1/4, exclusive.
1 1/4 to 1 1/2, exclusive.	4	4.5	5	6	8	8	9	10	1 1/4 to 1 1/2, exclusive.
1 1/2 to 1 3/4, exclusive.	3.5	4	4.5	5	7	7	8	9	1 1/2 to 1 3/4, exclusive.
1 3/4 to 2, exclusive.	3	3.5	4	4.5	6	6	7	8	1 3/4 to 2, exclusive.
2 to 2 1/2, exclusive.	2.5	3	3.5	4	5	5	6	7	2 to 2 1/2, exclusive.
2 1/2 to 3, exclusive.	2.5	2.5	3	3.5	4	4.5	5	6	2 1/2 to 3, exclusive.
3 or over.	2.5	2.5	3	3.5	4	4.5	5	6	3 or over.

V. FINISH.

Finish.

11. The finished material shall be free from injurious defects and shall have a workmanlike finish.

VI. MARKING.

Marking.

12. The name or brand of the manufacturer and the melt number shall be legibly stamped or rolled on all finished material, except that rivet and lattice bars and other small sections shall, when loaded for shipment, be properly separated and marked for identification. The identification marks shall be legibly stamped on the end of each pin and roller. The melt number shall be legibly marked, by stamping if practicable, on each test specimen.

VII. INSPECTION AND REJECTION.

13. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. All tests (except check analyses) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

14. (a) Unless otherwise specified, any rejection based on tests made in accordance with section 4 shall be reported within five working days from the receipt of samples.

(b) Material that shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer will be notified.

Rehearing.

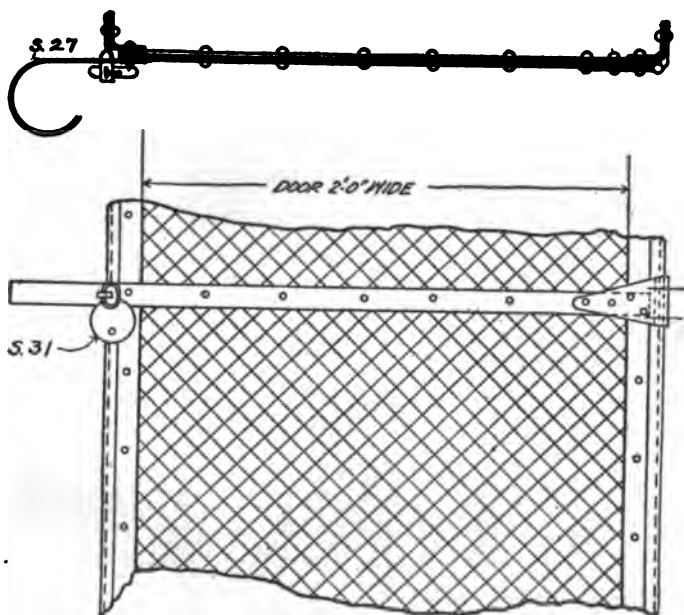
15. Samples tested in accordance with section 4, which represent rejected material, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

DISCUSSION OF TANK SPECIFICATIONS.**SAND-LINE CONSTRUCTION.**

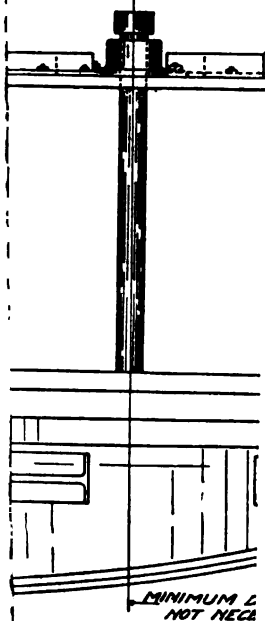
Although the modern steel tank of large capacity, as in use to-day, has proven itself admirably designed to withstand the pressure brought to bear upon it from within, it is, nevertheless, poorly equipped against wind stresses from without. The type of steel roof with steel supports described in the foregoing specifications is considered by many engineers to be sufficiently rigid to insure the tank against any damage from the wind. Nevertheless, although the writer has visited practically all the large oil-storage centers in the United States, and has not found a single properly constructed steel-topped tank with steel roof supports that has collapsed during a wind storm, he believes that the so-called sand-line construction for overcoming wind stresses can not be too strongly recommended, and in localities subject to wind storms should be used in all types of large steel tanks—those having steel roofs as well as those with wooden roofs on wooden roof supports.

1. DOOR.

WITH
WELLY
25.5N.



ALUMINUM COVER &
REQUIRED - COMPLET



MINIMUM 2"
NOT NECA

ANK ROOF.

This method of wind bracing is of reasonable cost, is effective, and is easily applied to any tank. It consists of stringing $\frac{3}{4}$ -inch flexible steel cables across 4 diameters of the tank, and at such distances apart that the tank area is divided into 45° segments, giving the appearance, in horizontal projection, of spokes in a gigantic wheel. Two sets of cables are generally used—one in a plane about 10 feet above the bottom of the tank, and the other 20 feet above the bottom, the "spokes" in the two planes being staggered so that the shell in a 55,000-barrel tank is wind-braced at intervals of approximately 20 feet along its periphery. Some engineers place 3 sets of cables, the topmost being attached to the top angle iron. This precaution may well be used for wooden-roof tanks with wooden roof supports, but should not be necessary when steel construction is used throughout.

Formerly old sand lines that had been discarded from drilling rigs were used—hence the name. However, for obvious reasons, the use of such lines is not good practice. Cables about a drilling rig are seldom discarded until they have become badly worn and their tensile strength consequently so much decreased that there is danger that the line will break under any heavy strain, with disastrous results.

The lines are fastened to the shell of the tank by small angle irons riveted to it, or by through-going eyebolts each of which is provided with a nut, washer, and gasket on either side of the plate. At the center of the tank the lines are attached to a heavy steel ring surrounding the center post, and each radius or "spoke" is provided with a turnbuckle, so that a practically uniform tension may be obtained on all lines, and whatever adjustment from time to time is necessary to keep this tension constant can be made. As the center ring can easily be constructed in two sections, this type of wind bracing can readily be applied to completed tanks as well as to those in process of erection. The only precaution necessary is to see that the diameters upon which the lines are strung are chosen so as to clear the roof supports.

TANK ROOFS.

The tank roof specified is composed of material of sufficient thickness to permit calking. Some companies prefer to use a lighter plate and to get the necessary tightness at the seams by using a thread "weave" immersed in red lead and placed between the laps of the sheets before they are riveted together. This method cuts down the cost of construction by decreasing the amount of metal used, but is criticized by many on the ground that the light hydrocarbon gases rising from the oil will in time "cut" the saturating material of the thread "weave" and completely destroy the tightness of the joint. A further objection put forth is that the roof of a tank is the part

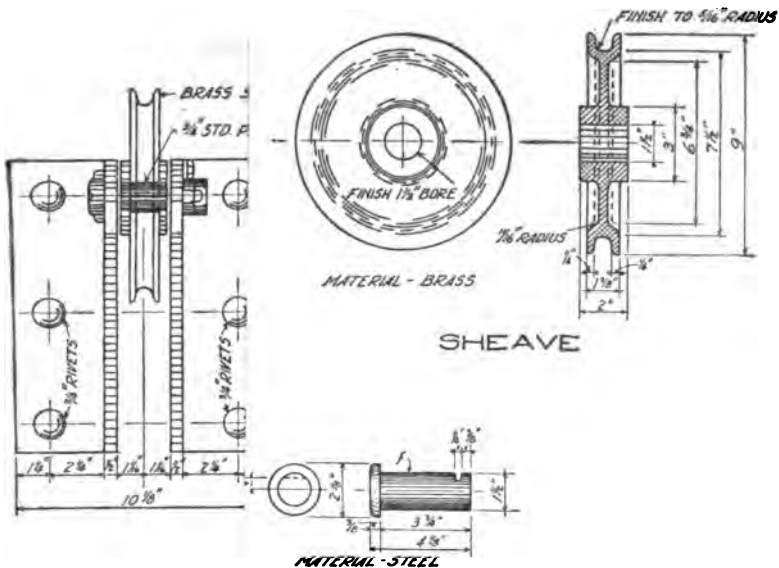
that deteriorates most rapidly owing to the action of these same hydrocarbon gases, especially if the oil contains any appreciable amount of sulphur, and a plate thinner than that which can be successfully calked (three-sixteenths of an inch) is undesirable. On the other hand, the objection can be raised to the use of the heavier material not only that it increases the cost of the tank, but that a roof is continuously subject to expansion and contraction stresses as well as to atmospheric pressures which cause it to "breathe." Thus the seams are subjected to distortion and it is questionable whether a calked joint can be kept tight.

SIZE OF PLATES.

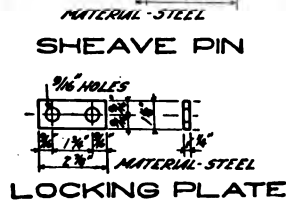
The size of plate ordinarily used for the shell of the tank is about 5 feet wide by 15 feet long (24 sheets to the ring). Six of such rings are required to obtain the necessary height of tank. Some companies, however, notably the Shell Oil Co. of California, are using sheets of sufficient width to require only 4 rings for a 30-foot tank. They are approximately 7 feet 6 inches wide and 18 feet long. By using plates of such size it is possible to eliminate two horizontal seams and four vertical seams, thus lessening the length of calked joints in the shell by more than 15 per cent. On the other hand, the amount of metal in the shell of a 4-ring tank is necessarily more than in a 6-ring tank because of the thickness of material required to satisfy proper engineering design and the impracticability of rolling a taper sheet. It is argued that if any extra thickness of metal is to be used, it should be put into the top or the bottom plates, as these are subject to the greatest deterioration by corrosive action, and not into the vertical shell. Further, the laps of sheets when properly riveted and calked seldom leak, and if leaks do occur, they can be easily repaired because of their accessibility.

SWING PIPES.

The swing pipes used by the various companies are all of the same general type, differing only as to details of construction. They range in size from 6 to 24 inches in diameter, depending upon the gravity of the oil to be handled and the size of suction line that they feed. Some operators equip their swing pipes with floats, making it possible to draw the oil from a point always at a certain definite distance below the surface by merely "slacking up" on the cable sufficiently to allow the float to carry the full weight of the pipe. There is the disadvantage, however, that should it be necessary at any time to raise the swing pipe when the tank is empty, the float makes the pipe unwieldy to handle, and if the pipe is made up of thin sheets of riveted plate, the usual practice, the resulting strain may produce leaky joints.

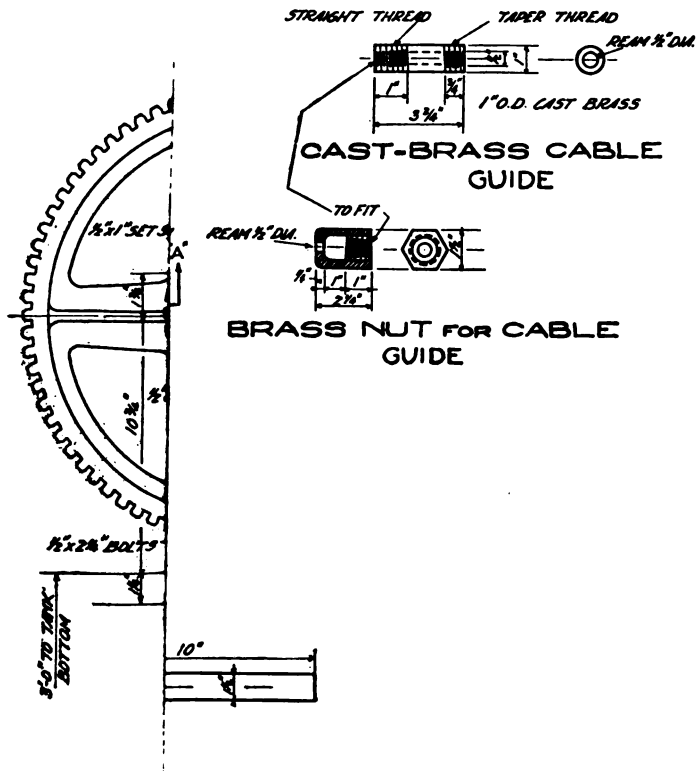


SHEAVE



SHEAVE PIN

LOCKING PLATE



CAST-BRASS CABLE GUIDE

BRASS NUT FOR CABLE GUIDE

SWIVEL JOINTS FOR SWING PIPES.

Swivel joints for swing pipes are of numerous types, varying in construction from two elbows connected by a short nipple, the threads of which furnish the necessary movement for raising and lowering the end of the pipe, to somewhat cumbersome and elaborate castings employing diverse types of stuffing boxes to obtain the necessary movement required for the swing.

The swivel joint prescribed in the specifications presented appeals to the writer as one of the best of the stuffing-box type. It is composed of two cast-iron tees, one of which may be a standard stock fitting, and the other arranged with stuffing boxes upon which the swing is made. This type of fitting can be easily and effectively supported from the bottom of the tank, and as the swing pipe has a bearing on both sides of its axis, the possibility of leakage occurring in the stuffing boxes by reason of the joint opening, as may occur if the bearing is on one side of the axis only, is eliminated.

STAIRWAYS.

Stairways should be of steel throughout. A wooden structure, even though it is kept well painted, which is seldom done, soon becomes a serious fire hazard because of the seasoning and checking of the lumber. In such a condition it is also a menace to employees on account of the lumber becoming brittle. Numerous varieties of steel stairways are in use. The one shown in Plate VI is perhaps as simple as any. Some companies have the top of the stairway about 2½ feet below the roof of the tank, the top tread being extended to form a small platform, as shown in Plate IX, A. The gage hatch is placed to the right of the center of the stairway close to the tank shell so as to be in easy reach of the gager from the platform. If the swing pipe is operated from the ground, the gager does not have to go on top of the tank, so that in obtaining his sample he is at all times protected by the hand railing on the stairway. Tank builders will usually supply without charge an iron ladder riveted to the shell. However, as this is at all times more or less coated with oil it can not be considered other than a positive danger to anyone required to use it, and especially to a man who has a case of sample bottles strapped to his back, and whose hands are necessarily smeared with oil. A tank without a stairway, preferably of steel leading from the ground to the roof is not adequately equipped.

EXPLOSION DOORS.

Many companies, especially those operating in California, do not provide explosion doors for tanks other than those used for the storage of light refined products, as gasoline and kerosene. As the California

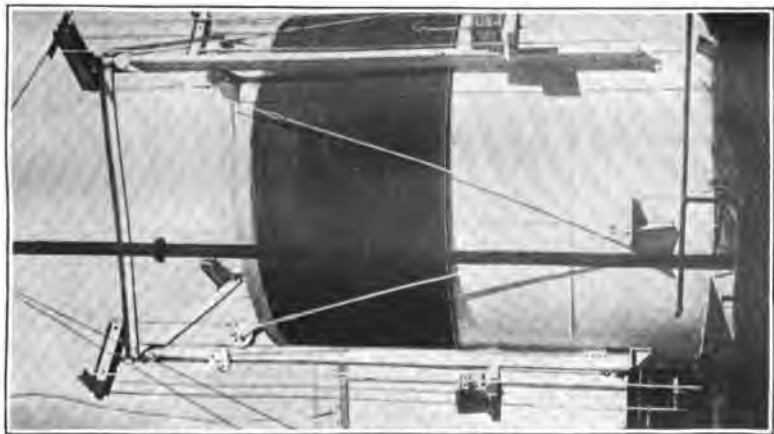
fields are seldom visited by electrical storms and the crude oils held in storage are practically all of low gravity and of asphaltum base, the dangers of fires from that source are comparatively remote, and the need of providing for such exigencies is perhaps not so urgent as in localities subject to electrical storms. However, in those sections where electrical storms are common (which seem to include all fields in the United States except those in California) it is believed that explosion doors should be provided for all storage tanks whether they contain crude oil or light refined products.

Although it is obviously impracticable to attempt to design explosion doors of sufficient area to take care of extreme conditions, as when a tank becomes almost completely filled with a mixture of hydrocarbon gases and air in the proportion best suited for rapid oxidation, it must be remembered that such conditions seldom, if ever, exist. Storage tanks when the oil is quiescent are usually kept full, and those from which oil is constantly being drawn and replaced would probably only occasionally contain the theoretical mixture conducive to explosion, there being most of the time a mixture either too rich in hydrocarbons or too rich in air. Therefore, the writer believes that where a tank is ignited, the chances are in favor of the possibility of saving at least the shell from injury, if not also the roof, by providing a reasonable number of vents through which a part of the pressure caused by an expansion of gas may be relieved. Eight explosion doors, each having an area of approximately 9 square feet, are prescribed in the specifications.

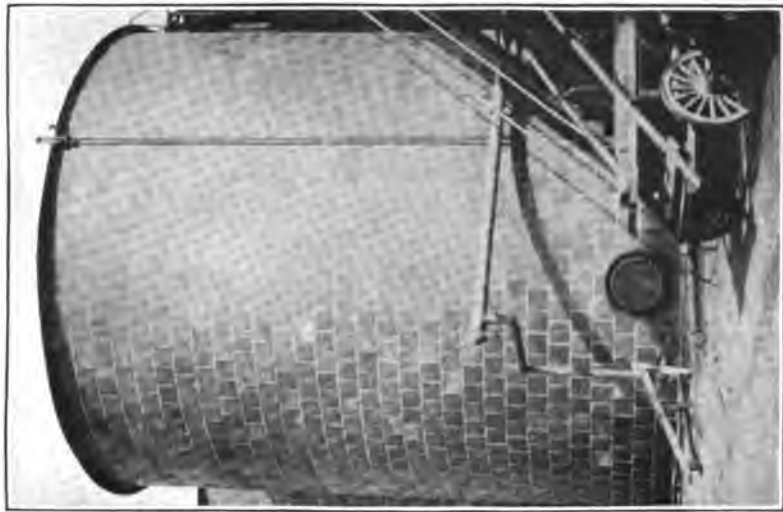
This type of door consists essentially of an aluminum plate $\frac{1}{4}$ inch thick which covers a circular hatch, and has a flange near its circumference fitting into a trough about 2 inches deep, surrounding the upper edge of the hatch. The trough is filled with a mixture of paraffin and oil, or sand and oil, to form a seal. The cover plate slides on a brass rod 2 inches in diameter, as shown on Plates VII and X, A. The upper end of the rod is supported by a plate 18 inches above the top of the hatch, which is held in place by angular supports $2\frac{1}{2}$ by $2\frac{1}{2}$ inches by $\frac{1}{4}$ inch. This rod fits in babbitt bearings at the top at the point where it passes through the aluminum plate, and in the spider beneath the plate. It is supported at the top bearing by a metal cap and hangs loose so that it is free to move on all three bearings if necessary. If an explosion occurs the pressure on the bottom of the aluminum plate is of the same intensity over its entire area. Should the bearing between the plate and the brass guide rod stick, the plate could still move upward by carrying the rod with it. When the pressure is released after the escape of the gas, the plate slides down the rod by its own weight and closes the opening.



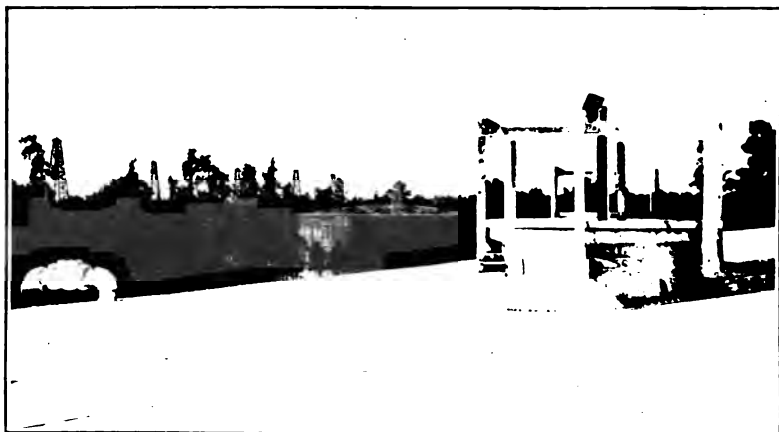
A. ALL-STEEL STAIRWAY FOR OIL TANK.



B. GASOMETER.



C. TILE-ENCASED TANK.



A. EXPLOSION DOOR AND VACUUM RELIEF VALVE.



B. "SHEEP'S FOOT" TYPE OF ROLLER.



C. WETTING DOWN LOOSE MATERIAL IN RESERVOIR BED.

VACUUM RELIEF VALVES.

A good type of vacuum relief valve to permit air to enter the tank when oil is being withdrawn is shown in Plate X, A. This consists of an ordinary stock swing-check so mounted that the check will operate to relieve a pressure from without. The lower face of the outside elbow is usually fitted with a flange and a fine-meshed wire gauze.

TANKS WITH WOODEN ROOFS.

Many companies, especially those handling heavy oils, are still constructing tanks with wooden roofs. The roofs are composed of sheathing 1 by 6 inches or 1 by 12 inches, generally sized, but sometimes laid on rough, on rafters 2 by 8 inches, supported by girders 5 by 12 inches or 6 by 12 inches, resting on posts 6 by 6 inches. Footing blocks 2 by 8 inches and about 3 feet long are usually provided for the posts. The tops of the posts where girders join are also provided with corbels of the same size and material as the footing blocks. The posts are tied together in each successive ring by sway braces of material 1 by 6 inches, placed diagonally. Some builders also tie the rings of posts together at various points. This practice, however, is not general and is of questionable benefit as regards strengthening the structure.

The sheathing boards are usually covered with a good grade of roofing paper which is essentially a deadening felt rendered waterproof by having been immersed in a hot solution of asphaltic material, and then rolled under heat and pressure. Roof coverings are also built up with layers of building paper or burlap coated and stuck together with asphaltum, and having a pebble finish on top. Such coverings should not be applied to a newly constructed roof before it has had time to season thoroughly, as the lumber in seasoning will almost surely tear the covering apart in some places and badly pucker it in others.

Sheet iron is also used for a covering for wooden roofs. The writer has seen some such roofs so well constructed that to all appearances they do not leak water and are reasonably tight even to the passage of gases. This construction has the disadvantage that the nails used for fastening on the iron will soon become loose in the sheathing on account of the wood having shrunk or become brash. There is the danger therefore that during a storm the wind may get a foothold under a sheet so loosened and tear a considerable part of the iron from the sheathing. This same objection holds true with the paper-covered roof. Once the covering of a wooden roof is gone, the wind will often wreck the sheathing and rafters as well.

Wooden roofs and wooden roof supports are objectionable also as regards fire hazard. Although it may be possible to extinguish burning oil in a tank by steam or a blanket of foam, neither of these

methods is necessarily effective in putting out a fire on the roof, so that smoldering embers may be continually dropping back into the tank only to reignite the whole mass, no matter how often the blaze along the surface of the oil may have been quenched.

COST OF TANKS.

On account of the uncertainty of the market price of manufactured products generally, owing to the present European war, it is hardly feasible to estimate the cost of steel tankage based on present figures as six months or a year hence the estimate may be abnormally high or abnormally low. At the time of the outbreak of the war, August, 1914, a tank, such as the one described with steel roof, could have been built at a cost of 30 to 32 cents a barrel, depending on the location. At present the cost would be 42 to 45 cents a barrel, whereas wooden-roofed tanks, which a little over three years ago were being erected for 25 to 27 cents a barrel, are now worth 37 to 40 cents a barrel. These figures are for completed tanks equipped with necessary swing pipe and fittings, and closed ready for the receipt of the oil, but do not include the grades for the tanks, nor pipe lines between tanks.

CONCRETE RESERVOIRS.

As stated at the outset, only concrete-lined reservoirs are here described in detail. Although a few companies at present store oil in earthen reservoirs without concrete linings, the writer has been impressed with the fact that even the officials of these companies do not in any way recommend this type of storage, but state that they are using it only as an emergency measure, or for heavy asphaltic base oils, which, owing to an overproduction, had first been stored for so long a time in tanks that practically all the lighter more volatile products had disappeared before they were put into the earthen reservoirs. The majority of such containers have been lined with several feet of clay, or some other close-grained impervious earth.

Most of the concrete-lined reservoirs in use in the United States are to be found in California. In that State there are an aggregate of 29 such reservoirs, having a total capacity of nearly 19,000,000 barrels. They are situated either in the oil fields themselves or at various points along the coast, and are used exclusively for fuel oils varying in gravity from 14° to 18° B. The lighter refining crudes are without exception stored in steel tanks.

SPECIFICATIONS FOR CONCRETE RESERVOIRS.

Typical specifications for this class of containers are presented below. The particular container described has an extreme outside

diameter of 488 feet, a total depth of about 25 feet, and a slope on the sides of 1 to 1. The roof is constructed of wood covered with roofing paper. The specifications follow.

SPECIFICATIONS FOR CONSTRUCTION OF CONCRETE-LINED OIL-STORAGE RESERVOIR.

SECTION I.—GENERAL REQUIREMENTS.

(1) DEFINITION.

The ——— Company in itself, or by its duly authorized representative, shall be referred to in these specifications as the "Company."

The firm undertaking to furnish the material and erect the reservoir as herein specified, in itself, or by its duly authorized representative, shall be referred to in these specifications as the "Contractor."

At all times during the progress of the work the Contractor shall designate some person as his representative to whom instructions may be given by duly authorized representatives of the Company.

(2) LOCATION.

The reservoir shall be located on the land of the Company in sec. —, T. —, R. —.

(3) DRAWINGS.

The drawings listed below, showing the details of the construction of the reservoir, are hereby made a part of these specifications: Plates XI, XII, XIII, XIV, and XV.

The drawings and specifications are intended to supplement each other, so that the work described in the drawings and not mentioned in the specifications, or vice versa, is to be executed by the Contractor as if it were both mentioned in the specifications and shown on the drawings.

(4) SHAPE AND PLAN OF CONSTRUCTION.

The reservoir shall be circular in plan, as shown on Plate XI, and shall be constructed by making an excavation and constructing around the excavation, with the excavated material, an earthen embankment. The area within the inner crest of the embankment shall then be covered with a wooden roof, after which the bottom and the sides of the place inclosed shall be lined with concrete.

(5) DIMENSIONS, SLOPES, AREAS, AND CAPACITY OF EMBANKMENTS.

The dimensions of the reservoir are as follows:

Inside diameter at top, 488 feet.

Inside diameter at bottom, 437 feet 6 inches.

Maximum depth, approximately 25 feet 11 inches.

The slopes of the embankment shall be as follows:

Slope of embankment inside reservoir, 1 horizontal to 1 vertical.

Slope of embankment outside reservoir, 2 horizontal to 1 vertical.

Slope of embankment top of reservoir, 24 horizontal to 1 vertical.

The width of the embankment on top shall be 15 feet. The area of the bottom will be approximately 150,330 square feet. The area of the sides will be 53,200 square feet; total area, 203,530 square feet; capacity, in barrels of 42 gallons each, approximately 750,000.

(6) WORKMANSHIP.

All work in connection with the construction of the reservoir must be done in a neat workmanlike manner, and to the entire satisfaction of the Company, or its duly authorized representative.

(7) INSPECTION OF MATERIAL.

All material furnished by the Contractor as herein specified shall be of the best of its respective kind, and shall at all times be subject to inspection by the Company or its duly authorized representative, and any material that shall be found defective

and be condemned by the Company must be removed immediately by the Contractor and replaced by acceptable material.

(8) DAMAGES.

The Contractor shall at all times be responsible for damages to material that is stored in the vicinity of the reservoir site during the process of its construction, and the Contractor shall make good such damaged material by supplying new material from time to time at his own cost and expense as directed by the Company. The Contractor shall also be responsible for any damages done to the reservoir, or to any part of it, or to any property of the Company upon which the reservoir is situated, caused by the carelessness or negligence of any of his employees. The Contractor shall also be liable for all damages to tools, implements, and equipment furnished by him during the progress of the work.

(9) CARE OF MEN.

The Contractor shall have complete responsibility for the care of the men in his employ, and shall be liable for all damages by accident to such employees. He shall furnish the necessary commissary for feeding his men, and shall provide necessary tents, temporary houses, and equipment for sleeping quarters.

(10) INCOMPETENT EMPLOYEES.

The Contractor shall furnish only such men for the prosecution of the work as are competent in their particular line of employment. If any employee is judged incompetent by the Company or its duly authorized representative then the Contractor shall immediately remove such employee and shall not again employ him upon the work.

SECTION II.—EARTHWORK.

(1) NATURE OF THE WORK.

The work to be done under this section consists of excavating the necessary earth from the interior of the reservoir and depositing such excavated material in the embankments surrounding the reservoir, in accordance with plans hereto attached.

(2) EQUIPMENT.

The Contractor shall supply all the necessary labor, tools, and equipment, including picks, shovels, drills, "fresno" scrapers, wheel scrapers, road machines, tampers, and teams, and whatever equipment is necessary for properly carrying on the work.

(3) GRADE STAKES.

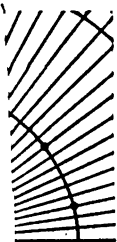
The Company shall place grade stakes wherever required about the reservoir, and the completed excavations and fills shall conform truly to the slope and outline as determined by such grade stakes, and the Company shall not be responsible for nor shall it pay for any work that does not conform to such grade stakes. The Contractor and his employees shall at all times exercise due caution in caring for grade stakes as set by the Company, and any employee willfully destroying such stakes shall be immediately discharged by the Contractor.

(4) EXCAVATION.

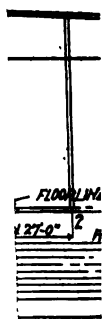
The exact amount of excavation shall be governed by the material that must be excavated, and shall be determined by the Company from time to time during the progress of the work. Should it be necessary in the opinion of the Company at any time to excavate more material from within the reservoir than originally intended, or to excavate material from borrow pits, the exact amount of such excavation shall be carefully determined by the Company by cross section, and the additional yardage shall be paid for at the same rate as the yardage from the original excavation.

(5) STRIPPING THE SURFACE SOIL.

The Contractor shall first strip the entire site of the reservoir, both that portion in cut and that portion to be covered by embankment, of all vegetable matter and top soil. This stripping shall extend to a depth of at least 8 inches below the surface and to whatever greater depth may in the judgment of the Company be required. The



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material so stripped shall be removed from the area and placed in fire levees surrounding the reservoir site, or at other points in the vicinity of the reservoir, as directed by the Company.

(6) OIL AND WATER DRAINS.

Two 12-inch oil lines and one 8-inch water drain shall be placed beneath the embankment, as shown on Plate XII, at such positions as shall be designated by the Company.

Ditches for these pipes shall be dug by the Contractor immediately after the surface soil has been stripped. Pipe shall be furnished and laid by the Company. The Contractor, however, shall do the work of backfilling the ditches, also of placing the concrete blocks, as shown on Plate XII.

(7) BUILDING UP THE EMBANKMENT.

The area beneath the embankment shall be plowed by the Contractor, thoroughly harrowed, and moistened with water to the satisfaction of the Company. The embankment shall then be built with material excavated from within the reservoir, or, if need be, from pits in the vicinity of the reservoir. The material may be excavated and placed in the embankment by wheel scrapers, "fresno" scrapers, or wagons. It shall, however, not be deposited in layers more than 3 inches thick, and where necessary road machines shall be employed to insure the proper spreading of the material in the embankment. Under no conditions shall material be dumped onto the embankment in a pile and not spread.

All material placed in the embankment shall be moistened with water before being loaded into the scrapers or wagons, and shall again be moistened after having been spread. Any excavated material from within the reservoir that, in the judgment of the Company, is not fit to be placed in the embankment shall be placed by the Contractor at a point outside the reservoir site, as designated by the Company.

When the material has been placed in thin layers in the embankment and moistened as specified, it shall then be tamped by at least two roller tampers of the sheep's foot type. Each tamper shall be drawn by a 4-horse team, and shall be driven around the top of the fill, making at least 10 complete circuits of the reservoir per hour.

Water for wetting material shall be furnished by the Company, and shall be brought by the Company in water mains surrounding the outer circumference of the reservoir and at a distance of about 20 feet from the outside toe of the embankment. The Contractor shall furnish and shall lay all necessary laterals from this water main into the reservoir site, and shall move such laterals from time to time as may be required by the progress of the work.

(8) BORROW PITS.

Where necessary, borrow pits shall be designated by the Company in the vicinity of the reservoir site. The nearest rim of such a borrow pit shall be at a distance not less than 200 feet from the outer toe of the reservoir embankment, and the farthest rim of such a borrow pit shall be at a distance not to exceed 400 feet from the toe of the embankment. If it is necessary to so locate a borrow pit that its nearest rim is a greater distance than 600 feet from the outer toe of the reservoir embankment, the Contractor shall receive extra compensation for the removal of such material as shall be determined on at the time.

(9) RUNWAYS TO EMBANKMENT.

In the construction of the embankment the Contractor shall build runways for the removal of the material from the excavation inside the reservoir to the embankment. These runways shall be located by the Company, and shall be spaced at a distance not less than 100 feet apart. The scrapers, wagons, teams, etc., in carrying the dirt from the excavation to the embankment shall be driven up one runway and shall return to the excavation along the top of the embankment and down the next adjacent runway.

(10) THE INSIDE SLOPE.

To obtain a homogenous and compact surface to the inner slope of the embankment, the inner slope shall be built and finished in the following manner. The embankment of the reservoir shall first be built up as above provided in these specifications. The excavation shall be so made that the inner slope shall be about the width of a wheel scraper beyond the line of the desired finished slope, beginning at the bottom of the reservoir which shall be excavated for a distance of about one foot below the position of the concrete lining. The inner slope shall then be built up by material excavated from within the reservoir, deposited by wheel scrapers in thin horizontal layers, and shall be moistened and thoroughly tamped by the sheep's foot tampers. This inner embankment, or earthen lining, shall be bound to the original embankment and slope by first plowing or otherwise roughening the original slope and embankment. When this lining is thus built up it shall be allowed to stand for at least 3 days before being trimmed to grade. The inner face of the embankment so built up shall then be trimmed to a true and even slope to conform with the dimensions of the reservoir as herein set forth.

(11) TOP OF THE EMBANKMENT.

The top of the embankment shall be built at least 2 inches higher than the finished top, and shall be made smooth and even and brought to proper grade.

(12) OUTSIDE SLOPE.

As herein specified, the outside slope of the embankment shall be 2 horizontal to 1 vertical. It shall be built up compactly, and neatly finished, and upon completion shall be oiled by the Contractor for a distance of 3 feet beyond the toe of the embankment. Oil shall be furnished by the Company on the ground and the Contractor shall provide the necessary equipment for sprinkling the oil upon the embankment.

(13) BOTTOM OF RESERVOIR.

The bottom of the reservoir shall be excavated to a subgrade 1 foot below the finished grade. It shall then be thoroughly plowed, harrowed, moistened, and compacted. Suitable refilling material shall then be spread over it to bring it up to the finished grade. The refilling material shall be spread on in thin layers as specified for the embankment, and shall be thoroughly moistened and rolled. The roller used on this work shall have a smooth surface, and shall weigh no less than 5 tons.

(14) EXCAVATION FOR POST FOOTINGS AND SWING-PIPE PIT.

When the bottom of the reservoir has been brought to the proper grade, the Contractor shall make excavations for the concrete footings for the posts, for the swing-pipe pit, and for the joint between the floor and the side slabs as designated by the Company. The Contractor shall remove from the inside of the reservoir all such material excavated, and shall place it at positions designated by the Company or its duly authorized representative.

(15) EXTRA WORK.

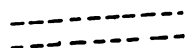
Extra work unless otherwise stated shall be done by force account, but under no conditions shall extra work be performed by the Contractor, or paid for by the Company, without written authority from the Company.

SECTION III.—ROOF.**(1) NATURE OF THE WORK.**

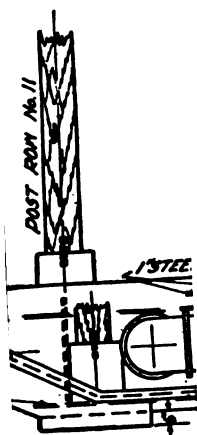
The work to be done, under this section, consists in the erection of a wooden roof over the reservoir as herein specified, and in accordance with drawings hereto attached.

(2) MATERIAL AND EQUIPMENT.

The Contractor shall supply all the necessary material, equipment, and labor for the construction of the roof. All such material shall be the best of its respective kind, and shall be subject at all times to the inspection of the Company or its duly authorized representative. It shall conform to the sizes as designated on the drawings.



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to be equipped with a properly constructed hatch placed at the head of the stairway as shown on Plate XII.

(8) NAILS.

The contractor shall furnish all nails required in the work, to be of sizes as designated in the specifications and drawings.

(9) ROOFING PAPER.

When the woodwork of the roof has been completed, before any roofing paper shall be placed in position, the sheathing shall be thoroughly swept and cleaned of all sawdust, dirt, gravel, chips, shavings, or other material, particular care being taken that no nails are left lying on, or partly imbedded in, the roof. All loose or projecting knots shall be removed, and knot holes exceeding 1 inch in diameter shall be covered with tin plates securely nailed on. The sheathing shall then be covered and made water-tight by placing one layer of 3-ply roofing paper of a quality to be approved by the Company or its duly authorized representative. This paper shall be laid in accordance with Plate XIV. Laps of paper shall be thoroughly cemented together and then nailed with No. 12 roofing nails, the maximum spacing between nails to be 1½ inches.

After the roofing paper has been laid in place, no unnecessary material of any sort shall be wheeled or carried over it, or stored upon it, and as little walking as possible shall be done upon it.

(10) ASPHALT AND GRAVEL COATING.

When the roofing paper has been placed in position as above specified, a heavy coating of hot asphalt, at least 3½ pounds per square yard, shall be applied, and a coating of hot gravel shall immediately be applied to the asphalt. As much gravel shall be used as is held by the asphalt. After cooling, the excess loose gravel shall be removed. Particular care must be taken that hot gravel is applied to hot asphaltum, and that a thorough bond is made between the gravel and the asphalt. If such a bond is not made in any part of the covering, the Contractor shall remove that part, including the roof paper, and shall replace it to the satisfaction of the Company.

(11) ROOFING GRAVEL.

The roofing gravel shall be furnished by the Contractor. It shall be composed of pebbles rejected by a screen having ¾-inch openings and passing through a screen having 1½-inch openings. Gravel shall at all times be subject to inspection by the Company or its duly authorized representative.

(12) WINCH BOX.

The Contractor shall install on the roof of the completed tank, as directed by the Engineer, two (2) standard iron winch boxes which will be furnished on the ground by the Company.

(13) DRAINS AND GUTTERS.

Gutters shall be constructed entirely around the outer edge of the roof, as shown on Plate XIV. The drains from these gutters and downspouts leading from the outer slope of the embankment shall be constructed as shown on Plates XIII and XIV. The galvanized-iron drains shall be furnished by the Contractor and shall be of No. 24 gage iron. The openings leading from the gutters to the downspouts shall be thoroughly and carefully flashed with roofing paper, and all joints shall be covered with hot asphaltic cement so as to make a water-tight job. All drains leading down the slope of the embankment shall be constructed of wood, as per detail drawing, and shall extend at least 10 feet beyond the toe of the slope.

(14) CLEANING UP.

Upon completion of the roof, the bottom of the tank and the inside slopes shall be thoroughly cleaned of all small pieces of wood, roofing paper, nails, refuse, etc., which shall be disposed of by the Contractor as directed by the Company.

(3) ROOF SUPPORTS AND PIERS.

Roof supports shall be wooden posts 8 by 8 inches, as designated on Plates XIII and XIV. The posts shall rest on concrete piers, as shown on the drawings, and shall be centered by one dowel pin, $\frac{1}{2}$ inch by 6 inches, in each pier. For the convenience of the Contractor piers may be poured in two sections, one pouring bringing the pier flush with the surface of the ground, after which the reinforcement fabric for the bottom may be placed in position, and the second pouring may be made, bringing the top of the pier to the desired grade and having the floor fabric embedded in it at the proper point so that fabric may form a continuous reinforcement for the floor slabs (see paragraph 5, section IV). The tops of the piers on the bottom of the reservoir shall be in the same plane, and the piers shall be kept damp for at least six days after having been poured before posts may be erected on them.

(4) ROOF GIRDERS.

The girders shall be of 4-inch by 14-inch material, and of lengths as shown on Plates XIII and XIV. They shall be fastened to the posts with $\frac{1}{2}$ -inch by 18-inch drift pins. Girders and posts shall be fastened together by knee braces, as shown on the drawings, of 2-inch by 6-inch material. Knee braces shall be bolted to posts and girders by at least two $\frac{1}{2}$ -inch carriage bolts. Corbels, as shown on Plate XIV, shall be placed on tops of posts in rows 2, 3, 4, and 5, and shall be drifted through with $\frac{1}{2}$ -inch by 24-inch drift pins, as shown.

(5) RAFTERS AND MUD SILLS.

All rafters shall be of 2-inch by 8-inch material, and of lengths as shown on drawings. The outer row of the rafters shall rest on a 2-inch by 12-inch redwood mud sill, as shown on Plate XIII, and shall be notched so as to bear on the full width of the mud sill. A line of 2-inch by 3-inch double bridging shall be placed between the rafters in the middle of each bay, with the exception of the bays of the outer row. In the outer row of bays three lines of such bridging shall be placed as directed by the Company. Bridging shall be nailed in position before sheathing is put on, and two 10d nails shall be used in the end of each bridging. The rafters shall be toe-nailed to the girders with 10d nails, using at least 3 at each rafter. Rafters that lap shall be thoroughly spiked together with 20d spikes, and where joints abut shall be spliced with 2-inch by 8-inch material and thoroughly spiked. The space between rafters at the embankments shall be completely closed by 2-inch by 8-inch material.

(6) SHEATHING.

The roof shall be sheathed with 1-inch by 8-inch sheathing surfaced on one side, furnished in assorted lengths from 8 feet to 16 feet. Sheathing to be No. 1 material, free from knots, pitch pockets or shakes. The roof shall be laid, as shown on Plate XIV, to break joints with roof paper.

Before the sheathing is laid the top of rafters shall be trimmed off with adzes where necessary to insure that sheathing will rest securely on each rafter and will lie smooth and flat. A space of approximately $\frac{1}{4}$ inch shall be left between each board to allow for swelling and shrinkage. Each board shall be nailed with at least three 8d nails on each rafter. All the roof supports and the sheathing, with the exception of a ring approximately 10 feet in width around the circumference of reservoir, necessary for handling the concrete materials, shall all be placed in position before any of the concrete material other than the post footings shall be poured.

(7) VENTILATOR, LADDERS, WALK, HATCH, ETC.

One ventilator, as shown on Plate XIV, shall be constructed on the roof at the center of the reservoir. Contractor shall also place a stairway from the bottom of the reservoir to the top on the inside as designated on Plate XII, and one stairway from the outside toe of the slope to the top of the embankment, to be located in the field by the Company. A wooden walk way shall be constructed by the Contractor from the edge of the roof to the center, having branches to the winch boxes. This wooden walk way shall be composed of 2-inch by 4-inch stringers, and 2-inch by 8-inch planks 2 feet wide, laid with intervening spaces of about $\frac{1}{4}$ inch. The roof of the tank is also



SECTION IV.—CONCRETE.

(1) NATURE OF THE WORK.

The work to be done by the Contractor under this section consists of constructing upon the sides and bottom of the reservoir, in a thoroughly workmanlike manner, a lining of concrete 3 inches in thickness, reinforced with metallic fabric as herein-after specified, and so carefully poured and compacted as to be as nearly as possible water-tight. Under no condition shall any of the concrete for the sides or floor be poured until the framework and sheathing of the roof, with the exception of the 10-foot strip around the circumference of the reservoir as hereinabove specified, shall have been erected. The piers for roof supports must, of course, be constructed before the erection of the roof, as provided in paragraph 3 of section III.

(2) MATERIALS, LABOR, TOOLS, ETC.

The Contractor shall furnish all materials, labor, tools, mixers, barrows, carts, cars, skips, engines, teams, wagons, etc., and any and all other tools and equipment necessary to perform the work as herein described.

(a) CEMENT.

A good grade of Portland cement satisfactory to the Company or its duly authorized representative shall be furnished by the Contractor. Cement may be supplied either in barrels or in sacks, at the option of the Contractor. It shall, however, at all times be subject to the inspection of the Company, the Company reserving the right to reject any and all cement that test shows to be not up to requirements.

(b) SAND.

The Contractor shall furnish the necessary sand for the contract. The sand must be clean and sharp and free from earth, clay, shell, gypsum, mica, or other injurious material.

(c) ROCK.

Crushed rock shall be furnished by the Contractor in sizes as follows:

One-half-inch rock, which shall be retained on a $\frac{1}{2}$ -inch mesh screen, and shall pass through a $\frac{1}{4}$ -inch mesh screen.

One-inch rock, which shall be retained on a $\frac{1}{2}$ -inch mesh screen, and shall pass through a 1-inch mesh screen.

It shall be of a quality approved by the Company, and shall contain no clay or earthy substances or volcanic ash.

(d) REINFORCING MATERIAL.

The reinforcing material used in the bottom and on the sides of the tank shall be welded metal fabric, having a 4-inch-by-4-inch mesh, and composed of No. 6 gage wires both ways. This fabric shall be furnished in rolls 86 inches in width and approximately 240 feet long. The Contractor shall supply, cut, and shape the reinforcing fabric as shown on Plate XV.

(3) WATER FOR CONCRETE.

The water for concrete shall be furnished by the Company and shall be supplied through the water mains surrounding the outer circumference of the reservoir, as provided for in paragraph 7, section II. The Contractor shall furnish and lay all necessary laterals from these water mains to the various positions along the edge of the reservoir where he may have his concrete mixers in operation.

(4) PREPARATION OF THE RESERVOIR FOR CONCRETE.

The final preparation for the pouring of the concrete shall be made by carefully bringing all parts of the bottom and inside of the reservoir to the finished grade. The Contractor shall also at this time excavate for the joint at the toe of the slope and shall remove all material so excavated, together with all material taken off in finishing to exact grades from the inside of the reservoir.

(5) PLACING REINFORCEMENT.

All reinforcement fabric for the bottom of the reservoir shall be laid before the roof is put in place, as specified in section III, paragraph 3, and must extend continuously along the bottom and sides of the reservoir through the foundation piers for the posts. Longitudinal splices shall be lapped at least one mesh and shall be wired together with No. 16 gage annealed iron wire to be furnished by the Contractor. All reinforcement must be properly stretched and made to lie flat. Transverse splices in reinforcement shall lap 24 inches. When the reinforcement is in place, and before pouring is begun, care must be taken that all stakes, pins, bolts, etc., used in laying and stretching the fabric are removed. The fabric must be so placed over the entire area that it can readily be pulled into position in the center of the concrete slab as the pouring progresses. Arrangement of reinforcing material is shown on Plate XV.

(6) JOINT AT TOE OF SLOPE.

A wooden joint of 1-by-6-inch material shall be placed in the concrete at the toe of the slope inside the reservoir, as shown in detail on Plate XII. The metal fabric laid upon the slopes and the bottom of the reservoir shall pass through the wooden frame in the joint, as shown on the drawing, and shall be so laid as to form a continuous reinforcement, tying sides and bottom together.

(7) PROPORTIONING CONCRETE MATERIAL.

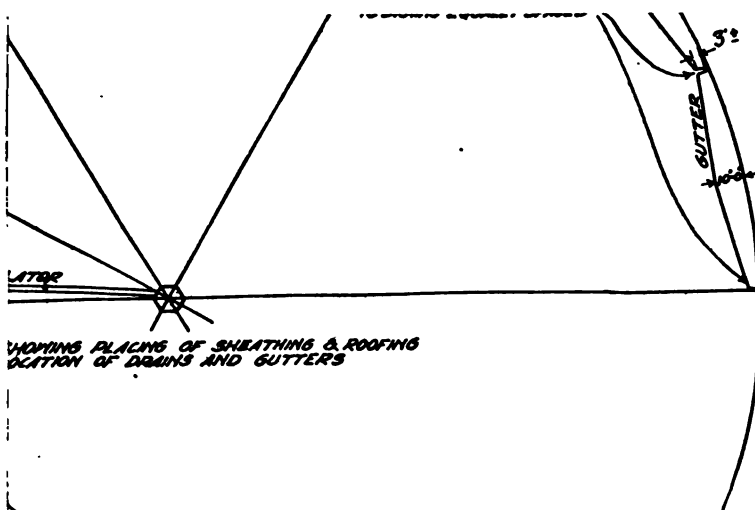
The concrete for the bottom of the reservoir and for the piers supporting the roof shall be composed of one part of Portland cement, two and one-half parts of sand, two parts of $\frac{1}{2}$ -inch crushed rock, and two and one-half parts of 1-inch crushed rock. The concrete for the sides of the reservoir shall be composed of one part of Portland cement, two and one-half parts of sand, and two parts of $\frac{1}{2}$ -inch crushed rock. The proportions of the various materials shall be very carefully measured at all times by the Contractor. The Company, however, reserves the right to change from this proportion as it sees fit, and no such changes shall in any way be construed to affect the contract price.

(8) MIXING AND POURING CONCRETE.

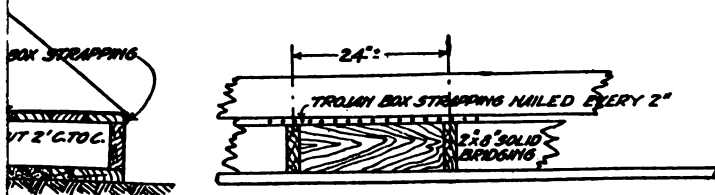
The bottom of the reservoir and the side slopes shall be thoroughly wetted before any concrete material is poured on them. In sprinkling, however, the Contractor shall see that no reinforcing fabric becomes dirty or muddy; and if any dirt does adhere to the fabric it shall be thoroughly removed before any concrete material is poured on it. The mixing shall be done in batch mixers of a form and type approved by the Company. No more water shall be added to the material than is absolutely necessary to cause the concrete to spread properly over the area to be covered. On both the floor and the side slopes a layer of concrete approximately $1\frac{1}{2}$ inches thick shall first be poured. The reinforcing fabric shall then be drawn up through the concrete and allowed to rest on top of it. As soon as the fabric has been drawn up, and before the first layer of concrete shall have obtained its initial set, a second layer shall be immediately poured, bringing the slab up to the required thickness. When the pouring has been completed, the surface of the concrete must be immediately tamped with wooden tampers and then finished smooth and close-grained by troweling. The Contractor must at all times exercise especial care that the position of the wire fabric is as nearly as possible in the center of the slab. He must also furnish men experienced in troweling and floating the surface of the concrete, in order that it may be made as nearly waterproof as possible.

(9) JOINTS IN CONCRETE.

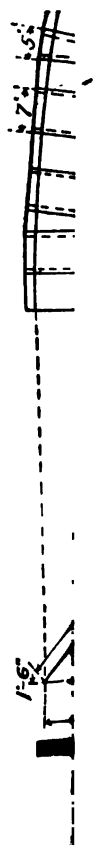
Upon the completion of a day's pouring the edges of concrete slabs shall be roughly beveled off. When work is resumed, this beveled edge shall be thoroughly cleaned, dampened, and well brushed with neat-cement grout before the next section of concrete is poured.



SHOWING PLACING OF SHEATHING & ROOFING
LOCATION OF DRAINS AND GUTTERS



DETAIL OF ROOFING AT EAVES



(10) SPRINKLING FINISHED WORK.

The Contractor shall keep all of the finished concrete moistened as directed by the Company until the final completion and acceptance of the reservoir by the Company.

(11) GROUTING:

Should small shrinkage cracks appear in any part of the floors or slopes at any time during the concreting, they shall be filled with a cement grout as directed by the Company. After the concrete has been allowed to stand for a period of 20 days, both the floor and the slopes shall be grouted with cement wash of a proportion to be determined by the Company or its duly authorized representative.

GENERAL DETAILS REGARDING RESERVOIR CONSTRUCTION.**CHOICE OF SITE FOR RESERVOIR.**

One of the most important factors upon which the success of a reservoir depends is the judicious choice of the site. The soil should be of homogeneous texture, preferably a sandy clay in which clay predominates. The site should be well drained in order that any surface waters that may percolate through the embankment and get behind the concrete lining may be carried away and not allowed to stand, thereby placing on the sides and bottom a hydrostatic pressure from without that may cause the concrete to crack when the reservoir is empty. It has been suggested that in large reservoirs drain tiles insuring the prompt removal of surface water might well be placed beneath the excavation. No site should be chosen such that the level of adjacent standing water, such as backwater from the arm of a river or bay, will at any time be above the level of the bottom of the completed reservoir. When strata or pockets of sand or other loose material extending into the subgrade are encountered they should invariably be removed for a distance of 3 feet or more below the finished excavation and then refilled to grade with selected earth, put on in thin layers and carefully tamped.

BUILDING EMBANKMENT.

In building up the embankment the "sheep's foot" type of roller tamper (Pl. X, B) has proved most effective. A "road machine" or road grader has been successfully used by some contractors for spreading the material, and a heavy harrow or a drag scraper has been used for breaking clods.

Wetting down the loose material is effective in enabling the tampers to build a compact embankment, in making the earth ride satisfactorily in the scrapers, and in keeping down the dust. The usual method of sprinkling is shown in Plate X, C.

On completion of the main embankment and the refill on the inner slope it is necessary to trim from the inner slope a foot or more of material to bring it to the true grade and to prepare it for the concrete lining. Grade stakes are set on radial lines at the top and at the inner toe of the slope at distances of approximately 10

feet apart around the circumference of the reservoir. Narrow trenches about 6 inches wide are then dug to grade by the use of mattocks and slope-level boards and 2-inch by 4-inch strips 38 feet long placed flat against the finished surface. The trimming between these slope strips is then done by hand or by especially devised scrapers ^a (Pl. XVI, A and B).

OUTSIDE SLOPE.

The outside slope of the embankment, shown in Plate XVII, A, when finished should be thoroughly sprinkled with oil, which not only prevents the washing of the earth by heavy rains but retards the growth of grass and weeds which when dry become a serious fire menace. It is good practice when the reservoir is in use to oil the slope two or three times a year, or often enough to keep it free from vegetation. A rapid and successful means of oiling is shown in Plate XVII, A. An ordinary 500-gallon tank wagon arranged with a sprinkler spout having an extended arm on one side so that the outer perforations will deliver the oil well toward the toe of the embankment is used. The lower part of the slope is reached from the ground surface.

ROOF.

As previously stated, the roofs of all the large reservoirs so far constructed have been of wood covered with roofing paper. In the opinion of the writer this type of construction is unsatisfactory, as it not only permits the sun's rays to heat the upper surface of the oil but it offers no resistance to the passage of the light hydrocarbon compounds that rise from the body of the oil by reason of such heating.

A reinforced-concrete roof would certainly be a much more permanent type of construction, and a concrete roof made sufficiently strong to uphold a foot or more of earth and tight enough to shed seepage water would be an ideal construction. By this means a low and practically constant temperature could be maintained within the reservoir at all times, and injuries to the concrete lining through expansion and contraction and losses by evaporation would be reduced to a minimum.

Various stages of the roof construction are shown in Plates XVII, B, XVIII, A, and XVIII, B.

CONCRETE LINING.

Too great stress can not be placed on the necessity of thoroughly mixing and tamping the concrete lining, as imperviousness of the lining is quite as important as a proper backing for it. It is abso-

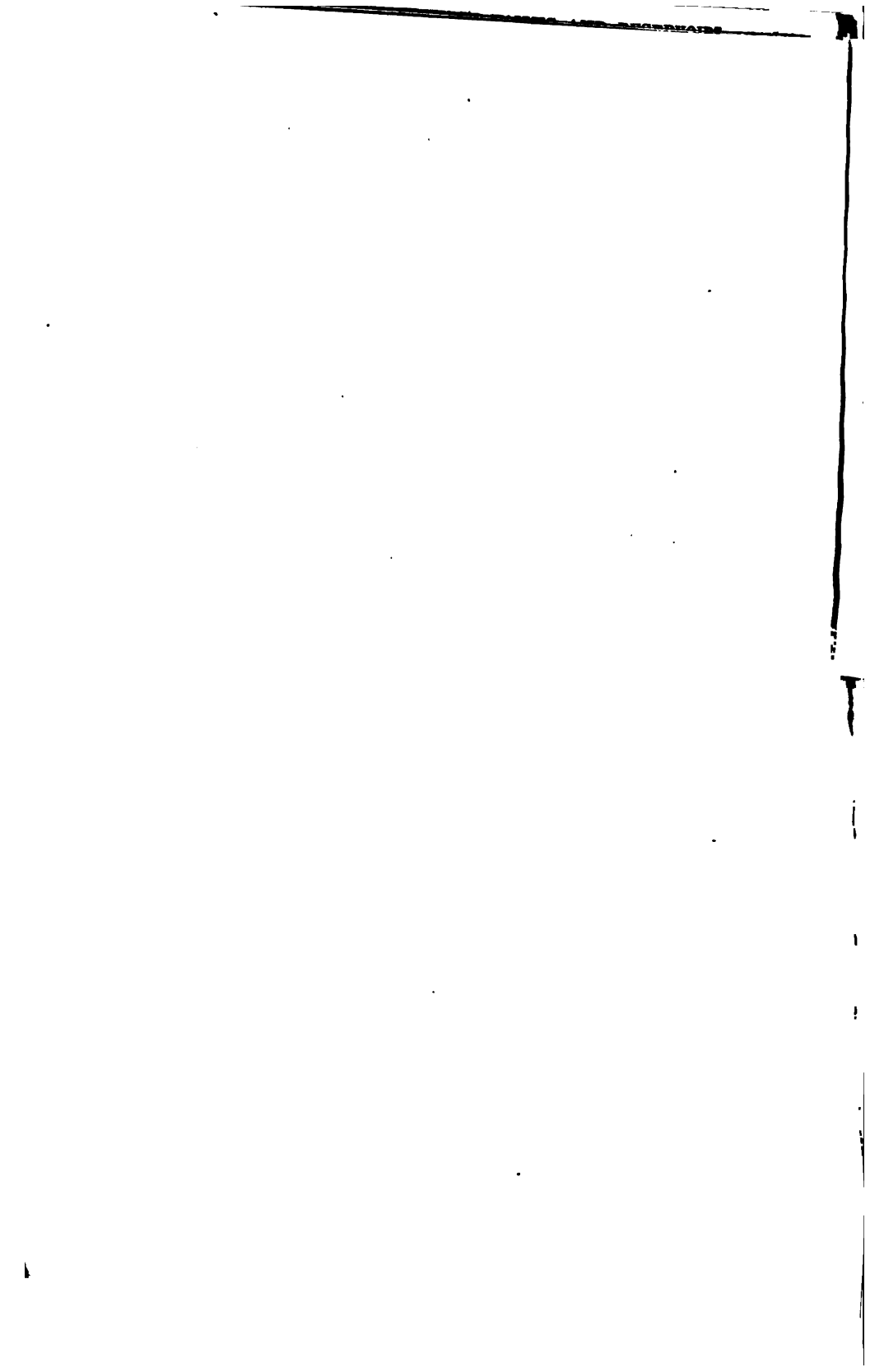
^a Cole, E. D., Concrete-lined oil-storage reservoirs in California; construction method and cost data: Proc. Am. Soc. Civ. Eng., vol. 41, August, 1915, pp. 1327-1350.



A. TRIMMING SLOPE BY HAND.



B. TRIMMING SLOPE WITH SPECIAL SCRAPER.



utely essential that the finished concrete be dense and have a dense close-grained glazed surface. To obtain this result a mechanical analysis of the aggregates to ascertain their proper proportions in the mix should be taken repeatedly during the progress of the work. The method for determining the proper proportions, described by Fuller and Thompson,^a has been successfully used.

EXPANSION JOINTS.

It will be noticed that the foregoing specifications make no provision for expansion joints in the concrete other than the joint between the floor and the side slopes formed by the small wooden form of L cross section. This is not strictly an expansion joint, as the reinforcement is carried through it from the sides to the bottom. It forms a convenient line to which to pour, and in the more recently constructed reservoirs the form has been removed entirely before the slope concrete has been poured. Excavation for this joint is shown in Plate XVII, *C*.

In the first reservoirs constructed various types of expansion joints were used, but none has proved satisfactory. In fact, more than one company has spent a considerable sum of money in removing entirely the expansion joints from some of their reservoirs, which they found to be leaking badly.

Reed,^b in a discussion before the American Society of Civil Engineers, stated that it is his "belief that expansion joints are not necessary in work of this type, provided there is sufficient reinforcement in the slab and the concrete is carefully cured." The writer is inclined to agree with Reed, especially if the reservoir is comparatively well filled at all times, and when fresh oil is added in any appreciable amount care is taken to see that it is reasonably cold and is delivered into the reservoir well toward the center of the oil already contained and not against the concrete lining. Even when it is necessary to withdraw all the oil from the reservoir there is no reason why a sufficient volume of water can not be placed in it to keep the air at all times cool and moist.

^a Fuller, W. B., and Thompson, S. E., The laws of proportioning concrete: Trans. Am. Soc. Civ. Eng., vol. 59, December, 1907, pp. 67-143.

^b Reed, R. J., Concrete-lined oil-storage reservoirs in California; construction methods and cost of data: Proc. Am. Soc. Civ. Eng., vol. 42, February, 1916, pp. 229-232.

TEMPERATURE VARIATIONS.

Temperature variations throughout the year in a storage reservoir filled with oil are surprisingly small, as is indicated by Table 3 following:

TABLE 3.—*Temperatures without and at various points within K. T. & O. Reservoir No. 2, Bakersfield, Cal.*

[Capacity of reservoir, 500,000 barrels; depth, 21 feet; depth of oil, 19 feet 9 inches (approximately); gravity of oil, 14° B.]

Date.	Atmospheric temperature, °F.	Temperature of oil, °F.			
		2½ feet from bottom.	7½ feet from bottom.	12½ feet from bottom.	17½ feet from bottom.
1914.					
June 1	76	57	57	60	65
July 1	87	62	62	62	69
Aug. 1	86	60	60	66	73
Sept. 1	60	62	61	64	72
Oct. 1	60	62	62	67	72
Nov. 1	62	64	64	65	68
Dec. 1	48	59	59	59	59
1915.					
Jan. 1	37	56	56	56	56
Feb. 1	50	54	53	53	53
Mar. 1	48	54	54	54	54
Apr. 1	58	53	53	54	55
May 1	56	55	55	55	59
June 1	70	56	56	56	62
July 1	80	57	59	63	62

Extreme variation in atmospheric temperature, °F..... 50

Extreme variation in temperature of oil 2½ feet from bottom, °F. 9

Extreme variation in temperature of oil 7½ feet from bottom, °F. 11

Extreme variation in temperature of oil 12½ feet from bottom, °F. 14

Extreme variation in temperature of oil 17½ feet from bottom, °F. 20

Temperatures taken at 7 a. m.

The atmospheric temperature was taken at 7 o'clock in the morning, so that the extreme variation in atmospheric temperature shown is not the maximum variation. The highest temperature for the period was 106° F. at 3 p. m. on August 1, 1914, and the lowest 32° F. at 4 a. m., January 1, 1915, so that the actual extreme variation in atmospheric temperature was 74°. It is safe to say, however, that the highest and lowest temperatures recorded for the oil near the bottom of the reservoir represent very nearly the actual conditions for the period.

EFFECT OF OIL ON CONCRETE.

Where proper care has been taken to make a dense compact lining in which all coarse material is well embedded below the surface there seems no doubt that an oil-tight structure can be made. The writer has repeatedly seen samples of concrete lining taken from the bottoms of reservoirs 20 feet in depth which have been in use for a period of



five years. These have shown practically no penetration whatever. Mr. H. B. Truett, chief engineer of the fuel-oil department of the Southern Pacific Railroad, states that he examined a 750,000-barrel reservoir belonging to the company after it had been in continuous use for several years, and found the concrete lining in practically perfect condition. A scratch with a penknife removed the oil from the surface of the lining and showed the concrete white and unattacked in almost every place examined, and he found numerous places where the oil could be wiped from the surface of the lining, leaving it scarcely discolored and as smooth and firm as the day it was put in.

W. E. Perdew, chemist for the same company, has made a study of the action of oil on oil-proofing materials and on what was determined by mechanical analysis of the aggregates to be a desirable mix of concrete.

The following abstract of a report made by him shows the results of his experiments:

Concrete blocks 6 by 12 by 3 inches were made from the same materials mixed in the same proportions as were used in reservoirs Nos. 3 and 4, section 7, Kern River. This mix in parts by volume was as follows:

Aggregate.	Proportion.
Cement.....	1.0
Sand.....	2.5
$\frac{3}{4}$ -inch rock.....	1.5
1 $\frac{1}{4}$ -inch rock	3.0

After these bricks had been thoroughly cured, dried, and brushed they were painted with various commercial and noncommercial oil-proofing compounds. They were then submerged, with one smoothly troweled untreated brick, under a 20-foot head of 14° B. oil kept, by means of steam coils, at a temperature of 120° F., and allowed to remain in the oil for 120 days. The following results were obtained with the non-commercial coatings:

Acid sludge—brick washed free of acid; not effective.

Hydrochloric acid (1:1)—supposed to fill mouths of pores with silica; not effective; makes concrete more permeable.

Sulphuric acid (1:1)—same result as with hydrochloric acid.

Glue and chromic acid—concrete brick painted twice with glue and then with potassium dichromate solution; exposed to sunlight two days and then submerged in the oil; failure.

Lead paint—paint made of red and white lead, linseed oil, and turpentine was applied to a concrete brick. Paint tended to blister and peel. Oil gained access to the brick through ruptures in the coating. Better than some coating materials, but not very effective.

Condensation products of phenol and formaldehyde—two bricks were painted with this mixture, one of which was baked before being put into the oil. Coatings on both failed on account of cracking.

Sorel cements—preparation consisted of powdered magnesium oxide mixed with some filler, such as powdered silica and magnesium chloride solution. The powder and the liquid were mixed to the consistency of thick paint and applied with a brush. The coating cracked so badly under the test that it was practically useless.

Perdew goes on to state that the commercial coatings were no more effective than the noncommercial, and that the smoothly troweled untreated brick showed as little penetration as any bricks tested. His report gives the following data regarding "an attempt to decrease the permeability of concrete by precipitating barium sulphate in it as it is being mixed."

Cement: Cowell.

Sand: Unscreened sand, same as was used in the reservoir on section 7-C, Coalinga.

No. 4: Twelve briquets made from sand and cement, 3:1, using 13.75 per cent water. No additions.

No. 5: Eight briquets made from sand and cement, 3:1, using 13.75 per cent water. 0.1 per cent by weight of powdered barium chloride was mixed with the dry cement and sand, and sufficient potassium sulphate dissolved in the mixing water to precipitate all of the barium as insoluble barium sulphate.

No. 6: Eight briquets made with sand and cement, 3:1, using 13.75 per cent water. 0.2 per cent by weight of powdered barium chloride was mixed with dry sand and cement before wetting. Sufficient sulphate ions added to mixing water to precipitate all of barium as sulphate.

No. 7: Eight briquets made from sand and cement, 3:1, using 13.75 per cent water. 0.5 per cent by weight of barium chloride was mixed with the dry sand and cement before mixing with the water, to which had been added enough sulphate ions to precipitate all of the barium as the sulphate.

All briquets were stored under water for 20 days. Then half of each lot was dried in an oven, weighed, and submerged under about a 12-foot head of 14° B. oil, whose temperature was about 120° F. The other half of each lot was placed in a cool, damp place. At the end of 3 days more, all briquets were broken, with the following results:

Data regarding concrete briquets tested for permeability.

[Total age of all briquets, 50 days.]

Lot No.	Average tensile strength of briquets in moist air.	Average tensile strength of briquets in hot oil.	Per cent by weight of oil absorbed.
	<i>Pounds per square inch.</i>	<i>Pounds per square inch.</i>	
4.....	265	325	6.3
5.....	290	280	7.2
6.....	285	280	7.2
7.....	280	280	6.6

It is evident that this method is useless for decreasing the permeability of concrete. In fact, it would seem that it increases it. The tensile strength of the different lots was not overly definite, owing probably to the short duration of the test. It would seem that the precipitation of the barium sulphate, or the resultant formation of potassium chloride, accelerates the hardening of the concrete, based upon the tensile strength of the briquets stored in the moist air. Also, the tensile strength seems to decrease with the increase of barium chloride and potassium sulphate. That the highest tensile strength recorded was that of the No. 4 briquets, which had been under hot oil, bears out these conclusions, and is accounted for by assuming that the heat hastened the hardening of the concrete, while the oil had not had time enough to disintegrate it appreciably.

Practically the same treatment was given to briquets made from Coalinga sand, finely powdered diatomaceous earth from Casmalia, Cal., and cement in the propor-

tion 15:5:2, and it was found that the tensile strength of the briquets was decreased and the permeability was increased.

The same test was also applied to briquets made with Coalinga sand, 1:3, to which was added in the mixing water 0.0041 per cent iron in slightly acid solution, with practically the same results regarding tensile strength and permeability.

The following tests were made on briquets placed in 14° B. oil (about 10-foot head), 120° F., for a period of 22 days. Tests for tensile strength were taken before the briquets were immersed in the oil.

Sodium silicate solution—causes decrease in tensile strength with increase of amount added; and causes increase in permeability with increase of amount added.

Crude oil (4 per cent to 9 per cent additions)—decreases tensile strength and increases permeability.

In conclusion Perdeu states:

The fact is again emphasized that dense concrete is the most impervious to oils of 13° to 18° B., even when the oil is heated to a temperature of 120° F. The penetration of oil through the sides of the bricks that were troweled (the tops of the bricks in the molds), and hence the densest, was the least in every case.

COST OF RESERVOIRS.

The cost of a reservoir such as covered by the foregoing specifications would be 10 to 13 cents per barrel of capacity, dependent on the situation and other governing conditions. On a basis of 11 cents, the cost would be distributed approximately as follows:

Cost of earthwork, cents.....	3.5
Cost of roof, cents.....	3.0
Cost of concrete lining, cents.....	4.5
Total, cents.....	11.0

An unlined earthen reservoir with the same type of roof construction would cost 7 to 9½ cents a barrel, and it is estimated that a concrete-lined reservoir with a concrete roof on concrete roof supports and covered with 2 feet of earth would cost about 30 cents a barrel.

The following figures for labor costs cover the construction of two 750,000-barrel reinforced-concrete-lined reservoirs built at Bakersfield, Cal., during the winter and spring of 1913-14:

Labor costs for two concrete oil reservoirs at Bakersfield, Cal.

Earthwork:

Excavating for embankment, per yard.....	\$0.22
Lining inner slopes with selected material, per yard.....	.51
Finishing floor, per square foot.....	.005
Excavating for pier footings, trenches, etc., per yard.....	.70
Trimming slopes, per square foot.....	.012

Roof:

Hauling lumber from cars (½ mile), per M.....	1.19
Framing lumber for roof, per M.....	1.60
Erecting roof, per M.....	3.80
Sawing sheathing, per M.....	1.35

Roofing:

Laying roofing paper, per square.....	\$0. 12
Hauling roofing gravel from cars ($\frac{1}{4}$ mile), per ton.....	. 25
Placing asphalt and gravel coating, per square.....	. 32

Concrete lining:

Hauling cement from cars ($\frac{1}{4}$ mile), per ton.....	. 54
Hauling sand from creek bed (2 miles), per yard.....	. 86
Hauling rock ($\frac{1}{4}$ mile from cars), per yard.....	. 50
Laying reinforcing metal on slope, per square.....	. 16
Laying reinforcing metal on floor, per square.....	. 06
Pouring concrete piers, per yard.....	^a 4. 63
Pouring concrete floor, per yard.....	^a 2. 51
Pouring concrete slope, per yard.....	^a 3. 46

The figures given are based on the following conditions:

Situation of reservoir, half mile from railroad.

Formation of soil, light sandy clay.

Excavators used, wheel and "fresno" scrapers.

Hours worked a day, 9.

Wage paid laborers, \$2.50 a day.

Wage paid carpenters, \$3.50 a day.

Wage paid concrete laborers, \$2.75 a day.

Wage paid concrete finishers, \$4.50 a day.

Wage paid foremen, \$6 a day.

LIFE OF RESERVOIRS AND STEEL TANKS.

A properly constructed concrete-lined reservoir with concrete roof would last for an indefinite period. The life of the modern steel tank is variously estimated. However, the consensus of opinion among the majority of oil men seems to be that a commercial steel tank such as is in use to-day, if placed on a carefully constructed foundation, and if properly maintained, should last, with the exception of the roof, for 35 to 40 years. The roof, if of wood, covered with roofing paper, would of course require repeated repairs during this period to keep it waterproof and, even though it were constructed with steel, parts of it might need to be replaced three or four times by reason of deterioration from light hydrocarbon gases and sulphur fumes.

Several oil tanks examined by the writer have been in use for 20 to 25 years, and their shells are to all appearances in almost perfect condition. One tank at the Standard Oil Co. refinery, Baltimore, Md., of 30,000-barrel capacity, has been in continual service for more than 35 years. This is a wrought-iron tank made from plates much lighter than those used at the present time for a tank of this capacity. The rivet spacing is also greater than is used in modern practice, which means that the tank was not designed with what is considered to-day an adequate factor of safety. For this reason for several years past

^a Including cost of rock, at \$1.00 per ton. All material except sand and gravel was furnished by the owner at the Southern Pacific R. R. one-half mile distant from the work.

it has been carried only about two-thirds full, and, so the superintendent states, will be cut down and replaced in the near future. The roof has been replaced several times, but the shell so far as can be seen is sound and in good condition.

LOSSES IN STORAGE.

BY SEEPAGE.

Oil losses by seepage from steel tanks and from well-constructed concrete-lined reservoirs can be considered practically nil. From unlined earthen reservoirs, however, seepage losses may be very large. It is difficult to determine just what these losses are for the reason that most of such reservoirs, as previously stated, are used as emergency containers; the oil put into them coming unmeasured from flowing wells.

However, there is a record of a 500,000-barrel unlined reservoir in the Kern River field, Cal., that had to be abandoned on account of the excessive seepage losses. Although the reservoir was in use only a short time, pits dug subsequently in the bottom disclosed that the oil had already penetrated for a depth of more than 20 feet.

Another company in the same field found that its losses from both evaporation and seepage from heavy oil of 14° to 16° B. stored in a 1,000,000-barrel reservoir over a period of six years, when the reservoir was kept approximately full, averaged 0.58 per cent a month, or 6.96 per cent a year. After the reservoir had been lined with concrete the losses were reduced to approximately 0.176 per cent a month, or 2.112 per cent a year. Assuming that the losses by evaporation were the same for the lined as for the unlined reservoir, which was practically the case, as oil was constantly being put into and withdrawn from the reservoir under both conditions, the saving of oil due to the lining was 4.85 per cent per year. In other words, if the reservoir were kept full the yearly saving at the present market price of oil (about \$1.00) would amount to \$48,500 a year, which, placing the cost of lining at 5 cents per barrel, would pay for that lining in a little more than a year's time.

LOSSES BY EVAPORATION.

If we knew definitely the volume of useful hydrocarbon products that "vanish into thin air" from the wells, the transportation systems, the storage farms, and the refineries of the United States in one single year's time we might well be staggered by the size of the figures. To form some realization of their gigantic proportions one needs only to stand in the vicinity of a flowing well newly brought in, and witness the volumes of gases rising like exaggerated heat waves from the well itself, from the flow tanks in which the oil is being collected, from the sump into which it has overflowed, and from

every surface exposed to the atmosphere. The greatest unmeasured loss, of course, takes place in the vicinity of the well. Nevertheless, this loss continues in a large measure, especially as regards light oils, through the gathering systems, the transportation systems, and the receiving tanks at the refineries, and even from oil of low gravity there is a continual stream of the light hydrocarbons escaping from its surface so long as it remains in storage.

The following data from Port Arthur, Tex., give a comparison of the losses in a wooden-roof tank and in an all-steel tank with tight roof, having one central vent pipe leading the escaping gases to a point outside the fire levee.

Comparative losses of oil from a wooden-roof tank and from a steel-roof tank.

Kind of tank.	Date.	Gravity of oil in tank.	Depth of oil in tank.	Loss.		Time in storage.	Percentage of loss.	Percentage of loss in a year.
				Inches.	Barrels.			
	1915.	°B.	Fr. in.			Mo. days.		
Wooden-roof.....	May 12	55.9	28 11	11½	1,759	1 10	3.39	30.5
	June 22	55.2	27 11½					
Steel-roof.....	May 5	54.7	29 3½	2½	363	1 17	.687	5.32
	June 22	54.6	29 1½					

The highest temperature recorded at Port Arthur between May 5 and June 22, 1915, was 100° F.

Another Texas company found, from "a record of the evaporation of naphtha stored in a wooden-roof tank and in a steel-roof tank for a period of six weeks, that the loss from the wooden-roof tank was 3.1 per cent, while the loss from the all-steel tank was 0.42 per cent." On this basis the annual loss from the wooden-roof tank would be 25.20 per cent, and from the all-steel tank 3.40 per cent, or a difference in favor of all-steel construction of 21.80 per cent. With gasoline at, say, 15 cents a gallon at the refinery this would amount to \$75,500 a year in a 55,000-barrel tank, indicating that it is the height of folly to attempt to store gasoline even temporarily in a wooden-roof tank.

The following information covers tank farms in Oklahoma and Kansas, the oil in the tanks having remained practically undistributed after the original filling.

Comparative losses from wooden-roof a tanks in different districts.

Situation of tank.	Date filled.	Volume of oil.	Dates of adding oil.	Volume of oil put in tank.	Total volume of oil put in tank.	Date of latest observation.	Good oil in tank.	Difference.	Sludge.	Loss by shrinkage (evaporation).	Average yearly loss by evaporation.		Average sludge settling during whole period.	Gravity of oil at time of latest observation.
											Period.	Per cent.		
Ramona, Okla...	July, 1906	35,568.09	{Mar., 1908 Jan., 1914	{Barrels. 1,734.07 1,465.93	{38,788.06 38,788.06	Nov. 1, 1916	34,163.56	4,604.53	1,112.06	3,492.47	{July, 1906, to March, 1908... March, 1908, to January, 1914 January, 1914, to November, 1916.	{1.84 .71 .30	Per ct.	• B. 32.9
Jenks, Okla.....	Apr., 1907	35,475.75	{Mar., 1909 Apr., 1914	{1,591.57 1,644.67	{38,711.96 38,711.96	do.....	32,865.39	5,846.60	2,233.17	3,613.43	{April, 1907, to March, 1909... March, 1909, to April, 1914... April, 1914, to December, 1916.	{2.35 .92 .40	.60	b 36.9
Caney, Kans.....	Jan., 1906	35,473.02	.....	.....	.....	Sept. 1, 1907	34,024.34	1,448.68	961.46	497.22	{January, 1906, to September, 1907 January, 1907, to February, 1908.	{.48 1.29	1.02	33.5
Neodesha, Kans.	Jan., 1904	34,540.05	{Feb., 1906 Jan., 1909	{926.85 731.39	{36,198.29 36,198.29	Sept. 1, 1910	32,761.19	3,437.10	1,386.19	2,060.91	{February, 1906, to January, 1909 January, 1909, to June, 1911.	{.73 .47	.57	d 31.3

a Wooden roof of each tank was covered with roofing paper and sheet iron.

b Gravity on Sept. 1, 1907.

c Volume on Sept. 1, 1907.

d Gravity on Sept. 1, 1906.

A report on ten 55,000-barrel tanks, with construction similar to that of the tanks represented in the foregoing table, stored with Cushing oil in the Cushing field, showed the following loss by evaporation:

Gross stock Nov. 1, 1915..... 540,869. 11 barrels of 39.7° B.
Gross stock Sept. 1, 1916..... 537,530. 77 barrels of 39.1° B.

Shrinkage..... 3,338. 34 barrels

Yearly loss by shrinkage (evaporation), 0.62 per cent.

Two tanks of Healdton oil stored at Fort Worth, Tex., showed the following results:

Shrinkage in one year of Healdton oil in two tanks at Fort Worth, Tex.

Tank No.	Gross stock Sept. 1, 1915.	Gross stock Sept. 1, 1916.	Shrinkage.	Sludge Sept. 1, 1915.	Sludge Sept. 1, 1916.	Increase in sludge.	Yearly loss by shrinkage (evapora- tion).	Yearly shrink- age of sludge.
	<i>Barrels.</i>	<i>Barrels.</i>	<i>Barrels.</i>	<i>Barrels.</i>	<i>Barrels.</i>	<i>Barrels.</i>	<i>Per cent.</i>	<i>Per cent.</i>
136 ^a	53,175.50	53,044.20	131.30	435.26	739.57	304.31	0.25	4.7
127.....	53,616.60	53,091.13	525.47	366.98	469.79	102.81	.98	5

^a This oil was allowed to stand in earthen sumps for a considerable time before being stored; hence the comparatively small loss by evaporation.

^b Gravity of oil, 28.6° B.

^c Gravity of oil, 28.1° B.

^d Gravity of oil, 28.4° B.

^e Gravity of oil, 27.6° B.

A Pittsburgh, Pa., refinery furnishes data regarding steel tanks of 55,000-barrel and 37,000-barrel capacity, having wooden roofs covered with two-ply roofing paper and over that 22-gage sheet iron. They were used for the storage of Pennsylvania crudes, the results being as follows:

Data regarding evaporation losses in two Pittsburgh, Pa., tanks.

55,000-BARREL TANK.

Date of observation.	Gravity of oil.	Oil in tank.	Remarks.
Sept. 3, 1914.....	^a B. 44.0	<i>Barrels.</i> 54,036.12	Pennsylvania crude.
Aug. 13, 1916.....	43.5	53,038.33	
Loss.....	.5	997.79	Loss for period, 1.94 per cent, or for a year on same basis, 0.96 per cent.

37,000-BARREL TANK.

Date of observation.	Gravity of oil.	Oil in tank.	Remarks.
June 19, 1914.....	44.5	36,068.51	Pennsylvania crude.
May 1, 1916.....	43.5	33,929.66	
Loss.....	1.0	2,138.85	Loss for period, 5.93 per cent, or for a year on same basis, 3.18 per cent.

Eight new 37,500-barrel steel tanks, having wooden roofs covered with tar paper, over which was sheet iron, were filled with Illinois crude of an average gravity of 33.1° B. The oil was allowed to remain in storage for a period of four years, showing the following results:

Evaporation losses from eight wooden-roof steel tanks filled with Illinois crude.

Period.	Average gravity.	Average loss in gravity.		Average loss in fluid.	
		° B.	Per cent.	Barrels per tank.	Per cent.
When filled.....	° B. 33.13				
First year.....	32.22	0.91	2.75	1,007	2.766
Second year.....	31.77	.45	1.39	476	1.308
Third year.....	31.35	.42	1.32	344	.944
Fourth year.....	31.24	.11	.35	215	.588
Total, four years.....		1.89	5.81	2,042	5.606
Average per year.....		.47	1.45	510	1.402

Data from a Middle-West corporation that handles large quantities of crude petroleum and operates extensively in Texas and Oklahoma show that its oil is kept moving so constantly that exact figures on evaporation losses can not be given, but they are believed to be approximately as follows:

Evaporation losses from Texas and Oklahoma crudes.

Grade of oil.	Gravity, ° B.	Annual loss, per cent.
Distillate.....	43 to 50	2.0
North Texas and north Louisiana crudes (light).....	30 to 40	1.5
South Texas and south Louisiana crudes (heavy).....	18 to 25	.7
Oklahoma crude.....	30 to 38	1.0
Oklahoma crude.....	38 to 41	2.5

The following tabulation, compiled by a California company, shows the losses from fresh oils stored for short periods of time while on the way to the refinery or to market. The tanks in which the oil was placed had wooden roofs, some of which were covered with sheet iron. The length of time during which the oil remained quiescent—that is, without additions or withdrawals—ranged from 5 to 30 days. If the time was less than 30 days the amount shown in the column headed "Loss for 30 Days" was computed on the basis of the total loss during the quiescent period. The tanks under observation were in various fields and the oils ranged in gravity from 13.4° to 28.5° B. Temperature readings were taken three times a day—at 7 a. m., at noon, and at 5 p. m., the average temperature shown being the average of these readings for the period.

The average loss per month varied from 0.06 per cent for the heavy oils to 2.5 per cent for light oils, and the loss per year, based on the monthly loss, varied from 0.72 to 30.07 per cent. The yearly loss, however, is obviously too high, as the monthly evaporation would not remain a constant quantity throughout the year, but would decrease somewhat from month to month.

every surface exposed to the atmosphere. The greatest source of loss of stored liquid fuel is the evaporation of the fuel. No matter what type of storage is a large loss, especially as regards the lighter oil products. The evaporation of the lighter oil products is a serious problem at the refineries and even from all of the oil stored in a terminal system of the light hydrocarbons contained in the oil is a loss as it passes in storage.

The following data from the American Petroleum Institute give a comparison of losses in a wooden-roof tank and in an all-steel tank with roof having the wooden tank roof leading the evaporating gas from beneath the roof.

Comparison of loss of oil from a wooden-roof tank and from an all-steel tank

Loss of fuel	Loss	Temperature		Time in storage		Loss per 100 gal.	Loss per 100 gal.
		Initial	Final	Initial	Final		
Volatility	Initial	72	72	1	1	1.0	1.0
	Final	72	72	1	1	1.0	1.0
	Loss	72	72	1	1	1.0	1.0
Insulation	Initial	72	72	1	1	1.0	1.0
	Final	72	72	1	1	1.0	1.0
	Loss	72	72	1	1	1.0	1.0

The highest temperature recorded at Port Arthur between May and June 22, 1915, was 100° F.

American Petroleum Institute found from a record of the evaporation of gasoline stored in a wooden-roof tank and in a steel-roof tank for a period of six weeks, that the loss from the wooden-roof tank was 25.25 per cent. while the loss from the all-steel tank was 0.42 per cent. On this basis the annual loss from the wooden-roof tank would be 25.25 per cent. and from the all-steel tank 3.40 per cent. or a difference in favor of all-steel construction of 21.85 per cent. With gasoline at, say, 15 cents a gallon at the refinery this would amount to \$3.28 a year in a 55,000-barrel tank, indicating that it is the height of folly to attempt to store gasoline even temporarily in a wooden-roof tank.

The following information covers tank farms in Oklahoma and Kansas, the oil in the tanks having remained practically undisturbed after the original filling.

Comparative losses from wooden-roof a tanks in different districts.

Situation of tank.	Date filled.	Volume of oil.	Dates of adding oil.	Volume of oil put in tank.	Date of latest observation.	Good oil in tank.	Difference.	Sludge.	Loss by shrinkage (evaporation).	Average yearly loss by evaporation.		Grav. of oil when tank was observed.	Grav. of oil at latest observation.
										Period.	Per cent.		
Ramona, Okla....	July, 1905	35,568.06	Mar., 1906 {Jan., 1914	Barrels. 1,734.07 1,455.93	38,768.06 Nov. 1, 1916	Barrels. 34,153.564	604.53	1,112.06	3,492.47	July, 1905, to March, 1908... March, 1908, to January, 1914... January, 1914, to November, 1916.	1.84 .71 .30	32.9	31.3
Jenks, Okla.....	Apr., 1907	35,475.75	Mar., 1909 {Apr., 1914	1,591.57 1,644.67	38,711.99 do.....	32,865.39	5,946.60	2,233.17	3,613.43	April, 1907, to March, 1909... March, 1909, to April, 1914... April, 1914, to December, 1916.	2.35 .92 .40	36.9	33.4
Cusey, Kans.....	Jan., 1905	35,473.02	.....	.....	Sept. 1, 1907	34,094.34	1,448.68	951.46	497.22	January, 1905, to September, 1907.	.48	33.5	32.5
Needesha, Kans.	Jan., 1904	34,540.05	Feb., 1905 {Jan., 1909	928.85 731.39	36,198.29 Sept. 1, 1910	32,761.19	3,437.10	1,386.19	2,050.91	January, 1904, to February, 1906. February, 1906, to January, 1909. January, 1909, to June, 1911.	1.29 .73 .47	31.3	32.7

a Wooden roof of each tank was covered with roofing paper and sheet iron.

b Gravity on Sept. 1, 1907.

c Volume on Sept. 1, 1907.

d Gravity on Sept. 1, 1905.

A report on ten 55,000-barrel tanks, with construction similar to that of the tanks represented in the foregoing table, stored with Cushing oil in the Cushing field, showed the following loss by evaporation:

Gross stock Nov. 1, 1915..... 540,869.11 barrels of 39.7° B. oil
Gross stock Sept. 1, 1916..... 537,530.77 barrels of 39.1° B. oil

Shrinkage..... 3,338.34 barrels

Yearly loss by shrinkage (evaporation), 0.62 per cent.

Two tanks of Healdton oil stored at Fort Worth, Tex., showed the following results:

Shrinkage in one year of Healdton oil in two tanks at Fort Worth, Tex.

Tank No.	Gross stock Sept. 1, 1915.	Gross stock Sept. 1, 1916.	Shrinkage.	Sludge Sept. 1, 1915.	Sludge Sept. 1, 1916.	Increase in sludge.	Yearly loss by shrinkage (evapora- tion).	Yearly settle- ment of sludge.
	<i>Barrels.</i>	<i>Barrels.</i>	<i>Barrels.</i>	<i>Barrels.</i>	<i>Barrels.</i>	<i>Barrels.</i>	<i>Per cent.</i>	<i>Per cent.</i>
126 ^a	b 53,175.50	c 53,044.20	131.30	435.26	739.57	304.31	0.25	0.5
127.....	d 53,616.80	e 53,091.13	525.47	366.98	460.79	102.81	.98	.3

^a This oil was allowed to stand in earthen sumps for a considerable time before being stored; hence the comparatively small loss by evaporation.

^b Gravity of oil, 28.6° B.

^c Gravity of oil, 28.1° B.

^d Gravity of oil, 28.4° B.

^e Gravity of oil, 27.6° B.

A Pittsburgh, Pa., refinery furnishes data regarding steel tanks of 55,000-barrel and 37,000-barrel capacity, having wooden roofs covered with two-ply roofing paper and over that 22-gage sheet iron. They were used for the storage of Pennsylvania crudes, the results being as follows:

Data regarding evaporation losses in two Pittsburgh, Pa., tanks.

55,000-BARREL TANK.

Date of observation.	Gravity of oil.	Oil in tank.	Remarks.
Sept. 3, 1914.....	^a B. 44.0	<i>Barrels.</i> 54,038.12	Pennsylvania crude.
Aug. 13, 1916.....	43.5	53,038.43	
Loss.....	.5	997.79	Loss for period, 1.84 per cent, or for a year on same basis, 0.95 per cent.

37,000-BARREL TANK.

June 19, 1914.....	44.5	36,068.51	Pennsylvania crude.
May 1, 1916.....	43.5	33,929.66	
Loss.....	1.0	2,138.85	Loss for period, 5.98 per cent, or for a year on same basis, 3.18 per cent.

Eight new 37,500-barrel steel tanks, having wooden roofs covered with tar paper, over which was sheet iron, were filled with Illinois crude of an average gravity of 33.1° B. The oil was allowed to remain in storage for a period of four years, showing the following results:

Evaporation losses from eight wooden-roof steel tanks filled with Illinois crude.

Period.	Average gravity.	Average loss in gravity.		Average loss in fluid.	
		° B.	Per cent.	Barrels per tank.	Per cent.
When filled.....	° B. 22.13				
First year.....	22.22	0.91	2.75	1,007	2.768
Second year.....	21.77	.45	1.39	476	1.308
Third year.....	21.35	.42	1.32	244	.944
Fourth year.....	21.24	.11	.35	215	.588
Total, four years.....		1.89	5.81	2,042	5.606
Average per year.....		.47	1.45	510	1.402

Data from a Middle-West corporation that handles large quantities of crude petroleum and operates extensively in Texas and Oklahoma show that its oil is kept moving so constantly that exact figures on evaporation losses can not be given, but they are believed to be approximately as follows:

Evaporation losses from Texas and Oklahoma crudes.

Grade of oil.	Gravity, ° B.	Annual loss, per cent.
Distillate.....	43 to 50	2.0
North Texas and north Louisiana crudes (light).....	30 to 40	1.5
South Texas and south Louisiana crudes (heavy).....	18 to 25	.7
Oklahoma crude.....	30 to 38	1.0
Oklahoma crude.....	38 to 41	2.5

The following tabulation, compiled by a California company, shows the losses from fresh oils stored for short periods of time while on the way to the refinery or to market. The tanks in which the oil was placed had wooden roofs, some of which were covered with sheet iron. The length of time during which the oil remained quiescent—that is, without additions or withdrawals—ranged from 5 to 30 days. If the time was less than 30 days the amount shown in the column headed "Loss for 30 Days" was computed on the basis of the total loss during the quiescent period. The tanks under observation were in various fields and the oils ranged in gravity from 13.4° to 28.5° B. Temperature readings were taken three times a day—at 7 a. m., at noon, and at 5 p. m., the average temperature shown being the average of these readings for the period.

The average loss per month varied from 0.06 per cent for the heavy oils to 2.5 per cent for light oils, and the loss per year, based on the monthly loss, varied from 0.72 to 30.07 per cent. The yearly loss, however, is obviously too high, as the monthly evaporation would not remain a constant quantity throughout the year, but would decrease somewhat from month to month.

A report on ten 55,000-barrel tanks, with construction similar to that of the tanks represented in the foregoing table, stored with Cushing oil in the Cushing field, showed the following loss by evaporation:

Gross stock Nov. 1, 1915..... 540,869.11 barrels of 39.7° B. oil
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Shrinkage..... 3,338.34 barrels

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Two tanks of Healdton oil stored at Fort Worth, Tex., showed the following results:

Shrinkage in one year of Healdton oil in two tanks at Fort Worth, Tex.

Tank No.	Gross stock Sept. 1, 1915.	Gross stock Sept. 1, 1916.	Shrinkage.	Sludge Sept. 1, 1915.	Sludge Sept. 1, 1916.	Increase in sludge.	Yearly loss by shrinkage (evapora- tion).	Yearly settle- ment of sludge.
	<i>Barrels.</i>	<i>Barrels.</i>	<i>Barrels.</i>	<i>Barrels.</i>	<i>Barrels.</i>	<i>Barrels.</i>	<i>Per cent.</i>	<i>Per cent.</i>
126°.....	b 53,175.50	c 53,044.20	131.30	435.26	739.57	304.31	0.25	0.57
127°.....	d 53,616.60	e 53,091.13	525.47	366.98	469.79	102.81	.98	.19

a This oil was allowed to stand in earthen sumps for a considerable time before being stored; hence the comparatively small loss by evaporation.

b Gravity of oil, 28.6° B.

c Gravity of oil, 28.1° B.

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Data regarding evaporation losses in two Pittsburgh, Pa., tanks.

55,000-BARREL TANK.

Date of observation.	Gravity of oil.	Oil in tank.	Remarks.
Sept. 3, 1914.....	°B. 44.0	<i>Barrels.</i> 54,036.12	Pennsylvania crude.
Aug. 13, 1916.....	43.5	53,038.33	
Loss.....	.5	997.79	Loss for period, 1.84 per cent, or for a year on same basis, 0.96 per cent.

37,000-BARREL TANK.

June 19, 1914.....	44.5	36,068.51	Pennsylvania crude.
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Loss.....	1.0	2,138.85	Loss for period, 5.93 per cent, or for a year on same basis, 3.18 per cent.

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Evaporation losses from eight wooden-roof steel tanks filled with Illinois crude.

Period.	Average gravity.	Average loss in gravity.		Average loss in fluid.	
		* B.	Per cent.	Barrels per tank.	Per cent.
When filled.....	* B. 33.13				
First year.....	32.22	0.91	2.75	1,007	2.766
Second year.....	31.77	.45	1.39	476	1.308
Third year.....	31.35	.42	1.32	344	.944
Fourth year.....	31.24	.11	.35	215	.588
Total, four years.....		1.89	5.81	2,042	5.606
Average per year.....		.47	1.45	510	1.402

Data from a Middle-West corporation that handles large quantities of crude petroleum and operates extensively in Texas and Oklahoma show that its oil is kept moving so constantly that exact figures on evaporation losses can not be given, but they are believed to be approximately as follows:

Evaporation losses from Texas and Oklahoma crudes.

Grade of oil.	Gravity, * B.	Annual loss, per cent.
Distillate.....	43 to 50	2.0
North Texas and north Louisiana crudes (light).....	30 to 40	1.5
South Texas and south Louisiana crudes (heavy).....	18 to 25	.7
Oklahoma crude.....	30 to 38	1.0
Oklahoma crude.....	38 to 41	2.5

The following tabulation, compiled by a California company, shows the losses from fresh oils stored for short periods of time while on the way to the refinery or to market. The tanks in which the oil was placed had wooden roofs, some of which were covered with sheet iron. The length of time during which the oil remained quiescent—that is, without additions or withdrawals—ranged from 5 to 30 days. If the time was less than 30 days the amount shown in the column headed "Loss for 30 Days" was computed on the basis of the total loss during the quiescent period. The tanks under observation were in various fields and the oils ranged in gravity from 13.4° to 28.5° B. Temperature readings were taken three times a day—at 7 a. m., at noon, and at 5 p. m., the average temperature shown being the average of these readings for the period.

The average loss per month varied from 0.06 per cent for the heavy oils to 2.5 per cent for light oils, and the loss per year, based on the monthly loss, varied from 0.72 to 30.07 per cent. The yearly loss, however, is obviously too high, as the monthly evaporation would not remain a constant quantity throughout the year, but would decrease somewhat from month to month.

TABLE 4.—*Loss of oil by evaporation from 13 tanks in California.*

[Capacity of each tank, 55,000 barrels, except as otherwise noted.]

TANK 1, LOST HILLS FIELD.

Month.	Average temperature of oil in tank.	Barrels stored.	Number of days.	Total loss.	Loss for 30 days.	Average per cent of loss on amount stored per month.	Average gravity at 60° F.	
1913.	° F.			Barrels.	Barrels.		° B.	Record of no value. Temperature not given.
August.....								Record of no value.
September.....		53,360	11	191	520		22.9	Record of no value.
October.....	81	49,200	9	114	380		23.2	Record of no value.
November.....	76							
December.....	62	53,000	10	220	690		23.8	
1914.								
January.....	63	35,000	11	115	312		22.8	Do.
February.....	63						23.9	
1916.								
January.....	58	5,500	12	76	120		24.6	
February.....	62	10,000	13	76	132		23.7	
March.....	68	9,800	20	114	171		23.5	
April.....	70	8,400	10	114	223		23.4	
May.....	82	48,000	10	115	343		23.7	
June.....								Do.
July.....	62	46,000	15	191	382		23.6	
August.....	64	34,900	11	78	207		27.5	
September.....	80	38,800	17	368	537		27.8	Do.
October.....								
November.....	66	49,200	9	76	253		23.6	
Total.....		455,000		1,765	4,297	0.943		Loss per year, 11.32 per cent.

TANK 2, LOST HILLS FIELD.

1913.								
August.....	96	52,200	22	173	236		23.0	
September.....		10,200	12	192	490		23.8	
October.....	83	52,800	13	754	174		23.4	
November.....	77	54,000	13	340	784		22.7	Looks excessive.

December.....	62	52,000	10	76	228	23.4	Record of no value.
1914.							
January.....	61	53,000	10	75½	225	23.1	
February.....							
1916.							
January.....	56	47,000	9	38	127	24.4	
February.....	60	5,500	24	115	144	24.8	
March.....	66	27,000	18	536	881	24.3	
April.....	76	6,000	30	454	454	23.3	
May.....	80	9,500	11	77	210	25.1	
June.....	88	9,400	14	153	328	25.5	
July.....	92	7,700	12	191	477	26.6	
August.....							Do.
September.....	90	37,500	7	115	492	27.9	
October.....							Do.
November.....	70	51,300	9	153	510		
Total.....		476,300		2,763	5,760	1.209	Loss per year, 14.51 per cent.

TANK 3, LOST HILLS FIELD.

1913.							Record of no value.
August.....	96½	53,500	11	170	463	24.1	
September.....							
October.....	78	49,800	7	57	240	23.4	
November.....	74	54,060	7	228	977	23.3	Do.
December.....							
1914.							
January.....	64	53,000	7	151	648	23.4	
February.....		54,000	16	226	420	24.8	
1916.							
January.....							Do.
February.....	64	10,500	9	76	253	25.7	
March.....							Do.
April.....	76	49,600	13	76	176	25.6	
May.....							Do.
June.....							Do.
July.....	92	13,100	17	191	337	25.9	
August.....	94	9,800	7	38	163	27.1	
September.....	90	10,700	8	115	432	27.2	
October.....	76	52,600	13	75	173	27.4	
November.....							Do.
Total.....		410,400		1,403	4,282	1.043	Loss per year, 12.52 per cent.

TABLE 4.—*Loss of oil by evaporation from 13 tanks in California—Continued.*

TANK 4, LOST HILLS FIELD.

Month.	Average temperature of oil in tank.	Barrels stored.	Number of days.	Total loss.	Loss for 30 days.	Average per cent of loss on amount stored per month.	Average gravity at 60° F.	
1913.	° F.			<i>Barrils.</i>	<i>Barrils.</i>		° B.	Record of no value.
August.....	.....	54,200	5	954	570	.....	22.8	Do.
September.....	79	11,500	21	286	409	.....	22.4	
October.....	.....	.....	.....	.....	.....	.....	.....	
November.....	64	54,000	10	236	678	.....	23.5	
December.....	.....	.....	.....	.....	.....	.....	.....	
1914.	.....	.....	.....	.....	.....	.....	.....	
January.....	64	53,000	13	151	378	.....	23.4	
February.....	63	54,000	13	114	270	.....	23.2	
1916.	.....	.....	.....	.....	.....	.....	.....	
January.....	56	12,900	11	38	104	.....	23.4	Do.
February.....	.....	.....	.....	.....	.....	.....	.....	
March.....	66	9,300	11	76	207	.....	25.0	
April.....	78	49,300	8	76	285	.....	25.3	
May.....	80	11,300	8	76	235	.....	25.7	
June.....	88	11,000	13	153	353	.....	25.8	
July.....	94	8,600	13	153	353	.....	25.8	
August.....	94	37,300	11	38	104	.....	26.9	
September.....	88	11,400	7	76	326	.....	27.4	
October.....	76	11,400	7	38	163	.....	27.6	
November.....	66	50,100	8	76	285	.....	27.8	
Total.....	.....	439,900	.....	1,672	4,770	1.162	.....	Loss per year, 13.94 per cent.

TANK 5, LOST HILLS FIELD.

Month.	Average temperature of oil in tank.	Barrels stored.	Number of days.	Total loss.	Loss for 30 days.	Average per cent of loss on amount stored per month.	Average gravity at 60° F.
1913.	.....	.....	.....	.....	.....	.....	.....
August.....	98	51,500	16	244	458	.....	23.4
September.....	.....	22,000	7	150	643	.....	23.2
October.....	82	24,700	19	249	493	.....	22.9
November.....	76	20,000	22	553	753	.....	22.8
December.....	60	53,000	31	188	180	.....	23.0

1914.									
January.....	60	50,000	11	114	312	.....	23.0		
February.....	63	53,000	10	75	210	.....	22.7		
1916.									
January.....	54	4,200	30	38	38	.....	23.1		
February.....	58	4,200	30	76	76	.....	23.0		
March.....	64	4,100	30	115	115	.....	22.8		
April.....	76	4,000	30	38	38	.....	22.5		
May.....	80	3,800	30	76	76	.....	22.3		
June.....	86	3,900	30	153	153	.....	21.9		
July.....	90	3,700	30	115	115	.....	21.2		
August.....	94	3,600	30	76	76	.....	19.5		
September.....	85	3,500	30	115	115	.....	19.0		
October.....	74	3,400	30	76	76	.....	18.7		
November.....	66	3,300	30	76	76	.....	18.1		
Total.....		385,500	.....	2,527	4,003	1,039	.....	Loss per year, 12.47 per cent.	
Total, tanks 1 to 5.....		2,167,700	.....	10,120	23,112	1,066	.....	Total average loss per year, 12.79 per cent.	

TANK 6, MIDWAY FIELD.

1914.							
January.....	60	38,800	8	57	214	.....	27.2
May.....	81	49,200	9	253	777	.....	26.3
Total.....	.....	88,000	.....	290	991	1.126	.....
							Loss per year, 13.51 per cent.

TANK 7, MIDWAY FIELD.

1914.								
January.....	58	53,000	10	295	885	.....	28.1	
February.....	62	50,100	12	57	143	.....	28.5	
Total.....	.....	103,100	.....	352	1,028	.997	.....	Loss per year, 11.96 per cent.

OIL-STORAGE TANKS AND RESERVOIRS.

Month.	Average temperature of oil in tank.	Barrels stored.	Number of days.	Total loss.	Loss for 30 days.	Average per cent of loss on amount stored per month.	Average gravity at 60° F.
1913.	° F.						° B.
July.....	.....	35,300	18	<i>Barrils.</i> 931	<i>Barrils.</i> 1,551	.....	23.9
August.....	.....	34,000	19	400	631	.....	27.4
1914.							
February.....	62	35,000	13	63	145	.....	28.5
May.....	70	33,400	7	265	1,136	.....	28.0
Total.....	.....	137,700	.....	1,659	3,463	2.506	.....
							Loss per year 30.07 per cent.

TANK 9,^c MIDWAY FIELD.

1913.							
August.....	35,100	21	426	609	.....	25.8	
October.....	34,700	8	120	450	.....	28.4	
	74						
1914.							
April.....	36,100	16	413	775	.....	26.7	
May.....	32,200	15	239	478	.....	26.1	
	76						
Total.....	138,100	.....	1,198	2,312	1.673	.....	Loss per year, 20.08 per cent.

TANK 10,^c MIDWAY FIELD.

October	1913.	82	35,300	9	289	940	.....	27.5
May	1914.	89	33,700	7	114	489	.....	25.9
Total			69,000		403	1,449	2.100	
Total, tanks 6 to 10			535,900		3,902	9,243	1.725	
								Loss per year, 25.20 per cent.
								Total average loss per year, 20.70 per cent.

TANK 11, AT PUMPING STATION NEAR REFINERY.

	(b)	29,000	84	427	152	0.534	24.0	Loss per year, 0.29 per cent.
1913.								
August to November.....								

TANK 12,^a KERN RIVER FIELD.

1912.								
October.....		36,000	31	48				
November.....		36,000	30	9			13.4	
December.....		36,000	31	8				
1913.								
January.....		36,000	31	13				
February.....		36,000	29	11				
Average per month.....		36,000		89	18	.06		Loss per year, 0.6 per cent.

TANK 13,^a KERN RIVER FIELD.

1912.								
October.....		36,000	31	28				
November.....		36,000	30	21			13.4	
December.....		36,000	31	27				
1913.								
January.....		36,000	31	9				
Average per month.....		36,000		85	21	.06		Loss per year, 0.72 per cent.

^a Capacity of tank, 37,000 barrels.^b Average temperature of oil in tank in August, 94°; in November, 70°.

A California company reports that 18° B. asphaltum-base oil placed in storage in a concrete-lined reservoir with wooden roof showed a loss of 5.52 per cent after a year's time, and that during this period the gravity of the oil was reduced to 15.5° B. So far as is known all of this loss was by evaporation. The same company goes on to say that "Fuel oil of more than 14° B. should not be stored in reservoirs. The evaporation and leakage increase in proportion to the rise in gravity. Our experience has been with concrete-lined reservoirs in the Kern field (California) with gravity of oil ranging about 14° B.; out of eight lined reservoirs our smallest average loss in one reservoir was 0.35 per cent a year; our greatest loss in one of these reservoirs for the same period was 1.92 per cent, and the average loss in all the reservoirs for the year was 1.056 per cent."

These reservoirs have wooden roofs covered with roofing paper, and similar in construction to the roof described in the specifications.

Actual figures taken by the writer from the oil-storage reports of another California company show the following yearly losses from three concrete-lined reservoirs.

Evaporation losses from three concrete-lined tanks in California.

Quiescent period.	Capacity of reservoir.	Depth of oil (approximate).	Gravity of oil.	Per cent loss for period.	Per cent loss, same basis, per year.
	<i>Barrels.</i>	<i>Ft. in.</i>	<i>°B.</i>		
Sept. 1, 1915, to Aug. 1, 1916.....	750,000	21 9	14	0.542	0.50
Do.....	750,000	21 10	14	.382	.42
Do.....	500,000	19 10	14	.630	.69

These reservoirs have wooden roofs, and all of the losses indicated so far as is known were from evaporation.

Table 5 following, comprising a compilation of foregoing data, would indicate the average losses by evaporation from various gravities of distillates and crudes. However, the figures can not be taken as a basis on which to estimate closely future losses, for the reason that although most of them seem fairly reliable, it must be remembered that petroleum is an extremely complex mixture of hydrocarbon combinations having various gravities and various boiling points. A crude oil, for instance, with a gravity of 40° B. may be composed of some of the heavier hydrocarbons and some of the very light hydrocarbons, whereas another oil, with the same gravity, 40° B., may be composed of hydrocarbon compounds varying little from that gravity. The first oil would lose rapidly by evaporation when placed in storage, whereas the latter, although originally of the same gravity, would evaporate much more slowly.

The summary does serve to show that there is a considerable loss from all grades of oil when placed in storage, and that the evaporation from some grades of fresh oil is alarmingly large. Although the figures are admittedly incomplete, as the majority of operators have no reliable information as to exact losses from evaporation, it is hoped that publication of the figures may assist to stimulate producers and refiners generally to a more systematic effort toward determining the real magnitude of such losses. When this is done the writer believes the inevitable result will be much more definite and systematic efforts toward overcoming these losses than are at present exercised.

TABLE 5.—Summary of losses of oil in storage by evaporation.

Gravity of oil.	Type of container.	Average monthly loss.		Remarks.
		Per cent.	Per cent.	
60 to 55 distillate	Wooden-roof tank, paper top.	27.8	27.8	Plain top; no water seal.
Do.	All-steel tank	4.36	4.36	Water topped and lagged.
Do.	do.	3.76	3.76	
50 to 45 distillate	do.	2.03	2.03	
44.5 to 41	Wooden-roof tank, sheet-iron top.	2.02	2.02	Pennsylvania crude.
41 to 38	All-steel tank	2.50	2.50	Oklahoma crudes.
38 to 30 crude	do.	1.00	1.00	Texas and Louisiana crudes.
Do.	Wooden-roof tank, sheet-iron top.	1.41	1.41	Kansas and Oklahoma crudes.
33 crude	do.	1.40	1.40	Illinois crude.
26 to 18 crude	do.	1.70	1.70	Texas and Louisiana crudes.
26 to 22 crude	do.	5.52	5.52	Fresh California crudes.
18 crude	Wooden-roof tank, paper top.	6.94	6.94	California crude.
16 to 14 crude	Unlined reservoir, wooden roof.	6.95	6.95	Do.
14 crude	Concrete-lined reservoir, wooden roof.	.66	.66	Do.
13.4 crude	Wooden-roof tank, paper top.	.66	.66	Do.

DIFFICULTIES IN OBTAINING RELIABLE DATA REGARDING EVAPORATION LOSSES.

In dealing with large bodies of oil as contained in reservoirs of 750,000-barrel to 1,000,000-barrel capacity the "personal equation" of the gager may make a considerable discrepancy in results. There is also the likelihood of applying an incorrect coefficient of expansion^a in making the necessary volumetric corrections occasioned by reason of the oil having a temperature above or below the normal. For exact work the coefficient of expansion for each oil in question should be determined. Two oils of similar physical characteristics seldom have the same coefficient of expansion. For instance, it is the custom of many companies in handling low-gravity oil to subtract from the volume, if the indicated temperature is above 60° F., and to add to it if below 60° F., an amount equal to 1 per cent of the indicated volume for every 20 degrees variance from the normal temperature, which is another way of saying that a coefficient of expansion of 0.0005 is applied. Suppose, however, that the actual coefficient of expansion was 0.0004 (or such that the applied correction would be 1 per cent for every 25 degrees variance in temperature), and that the reservoir under consideration is of 1,000,000-barrel capacity having the variance in temperature 10 degrees; the computed figures would then be in error by 1,000 barrels.

DEVICES USED FOR LESSENING EVAPORATION LOSSES.

Why does oil evaporate? The accepted theory regarding the constitution of matter and the nature of heat assumes that all liquids are composed of molecules which are held together by mutual attraction. When a liquid is warmed above -273° C. the molecules are in constant and rapid motion, and, as a result there are spaces between them. As heat is applied to the liquid the molecules move more and more rapidly and strike against each other with greater force, separating further against the force of cohesion. Molecules near the surface of the liquid and vibrating rapidly pass out from it. Some are drawn back again into the liquid by cohesion, but some escape into the air above the surface. If the vessel containing the liquid is open, in time all may escape. However, if the vessel is tightly closed the molecules can not escape from it, and even though it be only partly filled with liquid the air above the surface soon becomes so filled with vibrating molecules that the number leaving the surface of the liquid in a given time is just equal to the number going back into it. The air above the liquid is then saturated and evaporation ceases. If the temperature of the liquid in the closed vessel is increased, vaporization again takes place, but ceases as

^a See Crossfield, A. S., The coefficient of expansion of California crude oils and distillates: West. Eng. vol. 6, December, 1915, pp. 229-238.

soon as the air in the vessel above the liquid becomes saturated for that temperature. However, the pressure in the vessel is increased. If the warm saturated air is cooled some of the vapor condenses and returns to the liquid and the pressure is decreased.

Devices for preventing evaporation losses should be designed with two purposes in view—first, to keep the temperature of the oil in the vessel as low as possible, and, second, to make the container as tight as practicable.

WATER-SEAL TOPS.

Perhaps the most common method of decreasing evaporation losses in an oil-storage tank is by the water-seal top, shown in Plate XIX, A. This form of construction is usually applied to small tanks of 1,000-barrel to 5,000-barrel capacity such as run-down tanks in which naphthas and light refined products are received from the tail houses. The construction of the tank is similar to other steel tanks except that it has a flat roof constructed from riveted plate calked and made water-tight, which is placed about 6 inches below the upper edge of the shell. The space inclosed above the plate is then filled with water that can be kept constantly circulating, thus keeping the tank and its contents cool. The tank shown in Plate XIX, A, is also fitted with a relief vent (in the foreground) which permits the escape of gas through a water seal and allows air to be taken in, as when the tank is being emptied, through a swing check valve open to a pressure from without, but closed to pressure from within the tank.

Table 6 following shows the results of tests made with small tanks of 100-barrel capacity, some of which had plain sheet-iron tops and others water tops. Each water-top tank was also protected with a sheathing of 1-inch boards surrounding the sides and the top of the tank and at a distance of about 18 inches from it. The use of these protective devices decreased the losses by evaporation as much as 14 per cent.



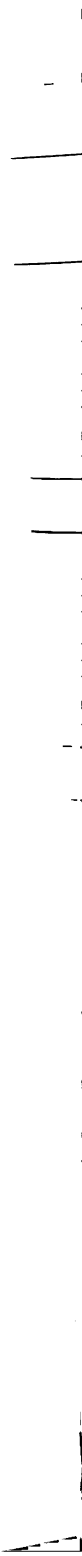
A. STORAGE TANK WITH WATER-SEAL TOP.



B. SPRINKLER FOR COOLING TANK.



C. BAFFLE PLATE AROUND EDGE OF ROOF TO DEFLECT WATER FROM SPRINKLER AGAINST SIDE OF TANK. NOTE STEEL STAIRWAY.



SECRET

—

[illegible]

1. Is there a...

2. Is there a...

3. Is there a...

4. Is there a...

5. Is there a...

6. Is there a...

7. Is there a...

8. Is there a...

9. Is there a...

10. Is there a...

P. M. ...
YALLO ...
...
...
... WALKER ...

TABLE 6.—Results of comparative 30-day tests for losses in plain-top and water-top tanks protected with sheathing.

[Nominal capacity of tanks, 100 barrels; galvanized iron; 9 feet 5½ inches in diameter; 7 feet 10½ inches high 16-gage iron.]

TEST 1.

	Date of test.	Temperature of oil.	Volume in tank.	Corrected gravity.	Losses.		Gravity.
					Barrels.	Per cent.	
Plain-top tank:	1915.	° F.	Barrels.				° B.
Test started.....	Sept. 28	92	92.57	23.4	.....	.....	.....
Test finished.....	Oct. 27	84	75.02	27.4	.....	.....	.....
Losses.....					17.55	19	6.0
Water-top tank:							
Test started.....	Sept. 28	86	93.72	33.6	.....	.....	.....
Test finished.....	Oct. 27	71	90.10	33.3	.....	.....	.....
Losses.....					3.62	3.86	.3
Saving by use of water top.....					13.93	15.14	5.7

TEST 2.

Plain-top tank:	1915.						
Test started.....	Nov. 17	76	81.43	31.0	.....	.....	.....
Test finished.....	Dec. 17	54	72.44	26.8	.....	.....	.....
Losses.....					8.99	11.04	4.2
Water-top tank:							
Test started.....	Nov. 17	71	82.44	30.0	.....	.....	.....
Test finished.....	Dec. 17	54	82.37	30.0	.....	.....	.....
Losses.....					.07	.1	.0
Saving by use of water top.....					8.92	10.94	4.2

TEST 3.

Plain-top tank:	1916.						
Test started.....	Aug. 8	90	85.88	29.9	.....	.....	.....
Test finished.....	Sept. 8	90	73.70	25.7	.....	.....	.....
Losses.....					12.18	14	4.2
Water-top tank:							
Test started.....	Aug. 8	90	84.66	29.9	.....	.....	.....
Test finished.....	Sept. 8	78	84.66	29.8	.....	.....	.....
Losses.....					.0	.0	.10
Saving by use of water top.....					12.18	14	4.1

MEAN TEMPERATURES.

Test 1.—Mean temperatures: 7 a. m., 75.6° F.; 12 m., 101.2° F.; 5 p. m., 80.7° F.; average, 85.8° F. (average temperature not strictly accurate as no midnight temperature was taken).

Test 2.—Mean temperatures: 7 a. m., 47.6° F.; 1 p. m., 62.8° F.; 5 p. m., 60° F.; 12 p. m., 50° F.; average, 55° F.

Test 3.—Mean temperatures: 7 a. m., 90.8° F.; 12 m., 92.5° F.; 5 p. m., 91° F.; 12 p. m., 72.3° F.; average, 86.7° F.

SPRINKLING TANKS WITH WATER.

Plate XIX, B, shows a tank-sprinkling device used by a Pennsylvania company. It is made on the principle of a lawn sprinkler and is placed on the roof at the center of the tank. During hot weather the spraying device is kept in constant operation. The water on

leaving the roof is deflected against the sides of the tank by the baffle plate shown in Plate XIX, *C*, so that it passes in a film over practically the whole outside surface of the tank.

GASOMETERS.

Plate IX, *B* (p. 18) shows a type of gasometer in use by the Shell Oil Co. of California for the collection of the light gases. The gasometer is attached to a battery of gasoline-storage tanks of gas-tight construction. Its purpose is to take care of the expansion and contraction, owing to changes in temperature, of the light gases filling the space between the surface of the gasoline and the tops of the tanks. If one tank in the battery is being filled while another is being emptied, the function of the gasometer is also to conserve the gases discharged from the tank being filled. Such gases ordinarily escape into the atmosphere, but the gasometer causes them to be returned to a tank being emptied. There seems no reason why such a system could not be applied to run-down tanks, and the like, a provision being made whereby any surplus gases not taken care of by the gasometer could be drawn off and condensed, or otherwise profitably disposed of.

TILE-ENCASED TANKS.

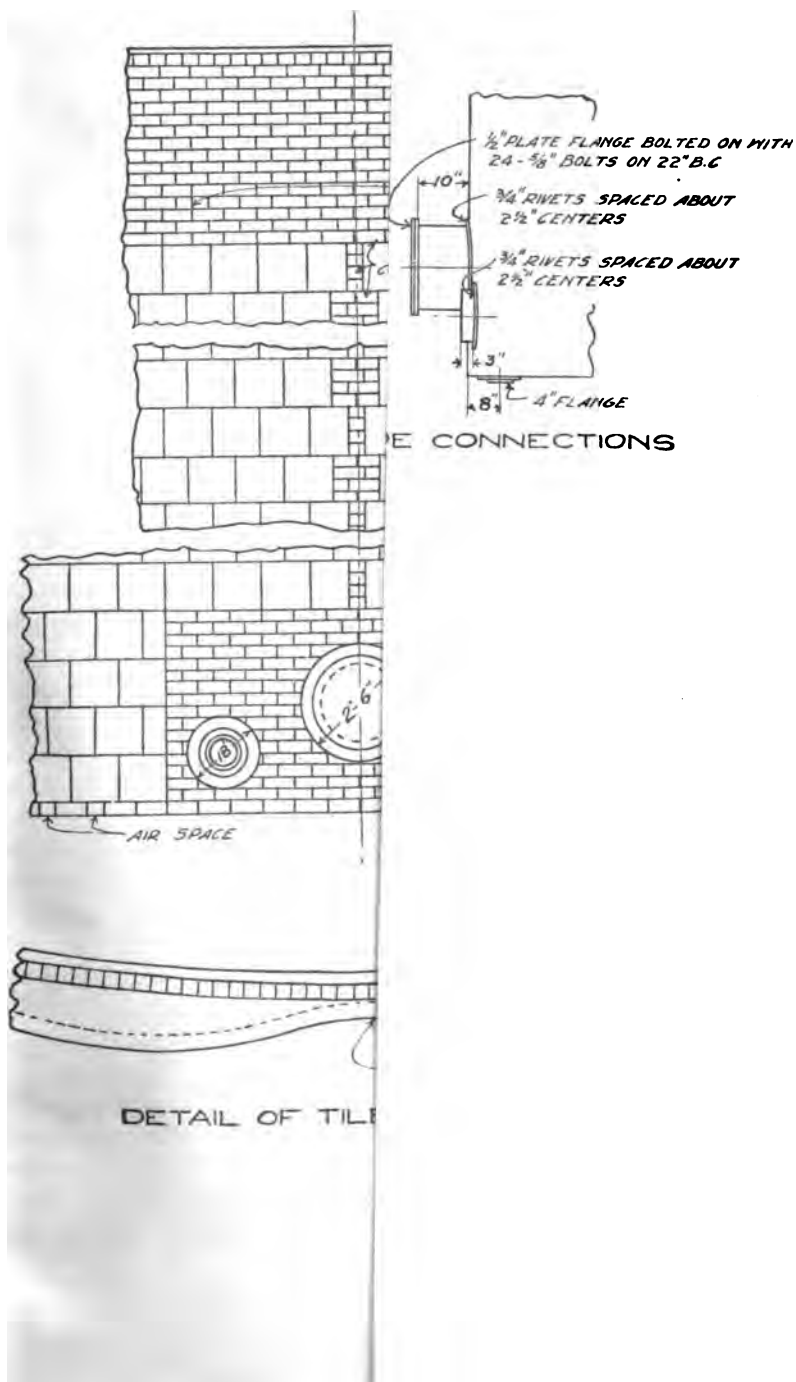
Tile-encased tanks (Pls. IX, *C*, and XX) are also in use. This type of protection, in the writer's opinion, would be much more effective if some type of casing were applied to the roof of the tanks as well as to the sides. The method of protection shown in Plate XX is said by the users to reduce evaporation losses 4 to 6 per cent. The tile used is ordinary hollow building tile such as is used in modern building construction.

BURYING TANKS.

Partly or wholly burying oil tanks in the ground is a common practice among some refiners. However, the ultimate economy is questionable, as depreciation of the shell from soil corrosion may be rapid, and leaks, unless relatively large, are hard to detect and expensive to repair.

CONCRETE TANKS.

Small reinforced-concrete tanks (Pl. XXI, *A*, *B*, and *C*), about 34 feet in diameter by 10 feet high, are being built by several refineries in various parts of Oklahoma. Each of these tanks has a capacity of about 1,500 barrels and is buried in the ground to within 3 or 4 feet of the top. The roof of the tank is 4 inches thick, the walls 8 inches, and the bottom 5 inches. The roof has a slope from the center to the edge of about 1 inch in 4 feet, and the bottom a slope from the side walls to the center where a sump 4 feet in diameter by



3 feet deep is constructed. A swinging pipe can be lowered into the sump when it is desired to drain the entire contents of the tank.

After the forms inside the tank have been removed from the walls and bottom these surfaces are given one to three coats of neat cement. When this has thoroughly dried, several coats of a commercial oil-proofing paint are applied.

One such tank has been in use by an Oklahoma company for the storage of 42° B. oil, since October, 1916. So far the tank has given complete satisfaction and the erection of additional tanks in the near future is proposed.

The estimated cost of concrete construction for various sizes of tank is as follows:

Estimated cost of various sizes of concrete tanks.

Capacity of tank, barrels.	Cost.	Capacity of tank, barrels.	Cost.
250	\$500	5,000	\$3,900
500	775	10,000	7,500
750	1,000	15,000	10,000
1,500	1,750	35,000	15,500
1,800	2,000	55,000	18,000
2,500	2,600		

In connection with the use of underground concrete tanks for the storage of oil it is interesting to note that the El Paso & Southwestern Railroad Co., at various places along its system, has for the past five years been storing fuel oil of 24° to 38° B. in circular concrete tanks about 12 feet in diameter by 6 feet deep. The bottoms of these tanks are 8 inches thick and the sides 6 inches thick, and each tank is covered by a concrete roof. The proportion of the mix is 1:2:4 and the largest rock 1 inch. The aggregate is thoroughly mixed, and care is taken that when it is placed in the forms it is well tamped and all air bubbles thoroughly worked out so as to insure as dense a concrete as possible.

Tanks that have been in use five years have been examined inside and out but no signs of leakage were discovered. At present the company has 12 such tanks, and their adaptability to oil storage has proved so satisfactory that more are in process of construction. No oil or waterproofing compounds are used.

A local company at San Antonio, Tex., has three such tanks, but of much greater capacity (180,000 to 400,000 gallons) in which oils ranging in gravity from 15° to 30° B. have been stored. One of these tanks has been in use 12 years. It was emptied recently and examined inside and out but no signs of leakage were found. The mix, as for the El Paso tanks, is 1:2:4 and the coarsest aggregate 1-inch rock.

At present a fourth tank is being constructed. This will have a diameter of 61 feet 6 inches, a depth of 18 feet, and a capacity of about 400,000 gallons. The bottom will be 17 inches thick and the sides 2 feet at the bottom tapering to 1 foot at the top; all heavily reinforced with steel rods. No oil-proofing compounds are used in any of these tanks.

A local electric company at St. Helena, Cal., built a rectangular reinforced-concrete tank in 1911. This tank is 16 feet long, 14 feet wide, and 5½ feet deep, having a capacity of approximately 10,000 gallons. The bottom is 20 inches thick and the sides 8 inches at the bottom, tapering to 5 inches at the top. Both the sides and the bottom were reinforced with steel rods. At the time the tank was constructed it was coated inside with a solution of sodium silicate. However, after 18 months of service the coating had become practically useless. The tank at this time was examined inside and outside by digging pits, but as no leakage was found no further attempt at oil proofing was made. Since that time the tank has been continually in service for the storage of oil varying in gravity from 15° to 26° B. The roof of this tank is made of wood covered with roofing paper. As a means of lessening evaporation losses and providing a run-off for rain water, as the wooden roof is practically flat, a second corrugated-iron roof of proper pitch has been constructed about 3 feet above the first roof, allowing free circulation of air between the two.

A refining company at Fort Smith, Ark., has two small rectangular reinforced-concrete tanks, one 10 by 14 by 6 feet, and the other 8 by 10 by 5 feet, which have been successfully used for the storage of oils up to 40° B. for the past seven years. There is nothing unusual in the construction of these tanks except that they were made of carefully selected aggregate well mixed and thoroughly tamped. No oil-proofing materials were used.

A large oil company at Tulsa, Okla., has recently completed a concrete reservoir about 200 feet square by 24 feet deep. The walls of the bottom 12 feet have a slope of about 1 : 1, and are supported by the natural earth backing, whereas the walls for the remaining 12 feet are vertical and backed by the excavated earth. The reservoir has a concrete roof, built on much the same principle as the floor of a modern class A building. The intention is to keep the roof of this reservoir covered by 2 feet or more of water and to allow the water to percolate down through the earth along the outside of the concrete.

The table following shows a list of companies that are using small concrete containers for the storage of oil, also the kind of oil stored, and whether the container has proved satisfactory.



A. EXCAVATING FOR A CONCRETE-LINED TANK.



B. FORMS FOR CONCRETE TANK.



C. COMPLETED TANK.

List of users of concrete tanks for oil storage.

Name of company.	Address.	Approximate size of container.	When installed.	Gravity of oil stored.	Remarks.
Santa Fe R. R. Standard Oil Co. Do.	Various places along system. Clearmont, N. J. do.	Feet. 25 by 40 by 12.	1910. 1914.	Heavy. Naphtha.	Partly satisfactory. Walls cracked, owing to settlement in foundation. Two old steel tanks lined with concrete, 1:2:4 mixture. Inside given coat of water glass. Satisfactory. Two-foot earth fill over top. Satisfactory. Satisfactory.
Williamson Milling Co. Southern Nebraska Power Co. Osark Refining Co. Do.	Clay Center, Kans. Superior, Nebr. Fort Smith, Ark. do.	12 by 20 by 10. 10 by 30 by 6. 44 by 18.	1910. January, 1917. do. 1912.	Heavy. 38° to 40° B., at 60° F. Average, 30° B.	Eight small concrete tanks 150 to 260 barrels each. Satisfactory. 50,000 gallons. Given coating 1:1 cement mortar. Satisfactory. Walls 12 inches thick at bottom; 8 inches thick at top. Satisfactory. 145,000 gallons. Satisfactory. For 10 inches thick. Wall 19 inches; all reinforced. Roof fell in 1914, but tank was otherwise in good condition and still being used.
Winters Cotton Co. Texas Light & Power Co. Desert Power & Mill Co. Houston Light & Power Co. Cotton Seed Oil Co.	Winters, Tex. Paris, Tex. Millers, Nev. Houston, Tex. Oklahoma City, Okla.	24 by 12. 34 by 11. 25 by 10.	1909. May, 1915. 1907. January, 1912. September, 1908.	Heavy. 28° to 30° B. Heavy. 21° to 30° B. Heavy.	These tanks. Partly satisfactory. Wall 34 inches thick at bottom, tapering to 21 inches at top. Bottom 42 inches. Satisfactory. Do.
Magnolia Compress Co. Muskegon Refining Co. San Antonio Gas & Electric Co. Do. Do. Do.	Houston, Tex. Muskegon, Okla. San Antonio, Tex. do. do. do.	25 by 16 by 8. 32 by 11. 45 by 15. 24 by 12. 46 by 16.	May, 1912. December, 1916. 1905. 1912. 1912. May, 1917.	23° B. 63° B. gasoline. 14° to 21° B. 24° to 28° B. 14° to 21° B. do.	400,000 gallons. Satisfactory. 1,200 gallons. Satisfactory. Four tanks. Satisfactory. Used for oil until July, 1911; since for water. Satisfactory. 30,000 gallons. Satisfactory.
Seymore Cotton Oil Co. Anadarko Cotton Oil Mill. Fairbanks, Morse & Co. Ada Gas & Electric Co. Charles City Gas Co. Shawnee Gas & Electric Co. Coden Refining Co. Dewey Portland Cement Co. Webster Oil & Gasoline Co. Indianapolis Refining Co.	Seymore, Tex. Anadarko, Okla. Beloit, Wis. Ada, Okla. Charles City, Iowa. Shawnee, Okla. Tulsa, Okla. Dewey, Okla. Oilton, Okla. Oklmulgee, Okla.	45 by 16 by 12. 35 by 16 by 10. 20 by 8. 22 by 10. 200 by 200 by 25. 23 by 7. 43 by 12.	1908. September, 1915. 1916. September, 1908. 1916. November, 1908. 1916. 1910. 1916. 1909.	Heavy. 26° B. Oklahoma crude. 23° B. 43° B.	Satisfactory. Thoroughly satisfactory. Satisfactory. Four tanks. One (16,000 barrels) still in use for hot crude. Only partly satisfactory. Others failed by settling.

e Diameter.

PAINTING TANKS LIGHT COLORS.

Many oil operators, especially throughout the eastern and the middle western fields, have adopted white or light-colored paints for storage tanks. It is reported that tests have demonstrated that evaporation from tanks painted white averages about 1 to 1½ per cent less than from tanks painted red, and about 2½ per cent less than from tanks painted black. These figures have not been verified, but tests made by the Institute of Industrial Research^a show that dark-colored paints absorb heat to a considerable degree, and paints presenting a highly glossy surface are less absorptive of thermal rays than those presenting a matte surface.

Experiments were conducted wherein small tanks containing benzine were painted in various colors (gloss finish) and then subjected to the rays of a powerful arc light for 15 minutes. At the end of that period the rise in temperature of the benzine was as follows:

Rise in temperature of benzine stored in tanks of various colors.

Color of paint or covering.	Rise in temperature, ° F.
Tin plate (tank plated with tin).....	19.8
Aluminum paint.....	20.5
White paint.....	22.5
Light-cream paint.....	23.0
Light-pink paint.....	23.7
Light-blue paint.....	24.3
Light-gray paint.....	26.3
Light-green paint.....	26.6
Red iron oxide paint.....	29.7
Dark prussian blue paint.....	36.7
Dark chrome green paint.....	39.9
Black paint.....	54.0

Tin plating and aluminum paint, as will be seen, gave the best results. However, neither of these finishes is practicable for outside work, as iron coated with tin corrodes rapidly, and aluminum paint soon loses its gloss and becomes flaky. The rise in temperature of the benzine in the tank painted black was 31.5° F. greater than the rise in the tank painted white, or 140 per cent. Although results such as obtained by these laboratory experiments could not be expected in actual practice, there is undoubtedly a decided advantage to be gained by painting storage tanks white.

^a Gardner, H. A., The heat-reflecting properties of colors applied to oil and gas storage tanks: Circular 44, Paint Mfg. Assn. of U. S., Educational Bureau, Sci. sec., January, 1917, p. 1.

COMPUTING VOLUME OF TANKS AND RESERVOIRS AND PREPARING GAGE TABLES.

METHODS OF OBTAINING FIELD DATA REGARDING TANKS.

The methods used by the various oil companies in obtaining the data necessary for computing the volumes of oil tanks and reservoirs, and for preparing gage tables are practically the same, differing only in minor details. As regards steel tanks there is much discussion as to just how many circumference measurements are necessary for accurate work. Some companies take only two (for a 6-ring tank), the lower one being at the middle of the second ring and the upper as

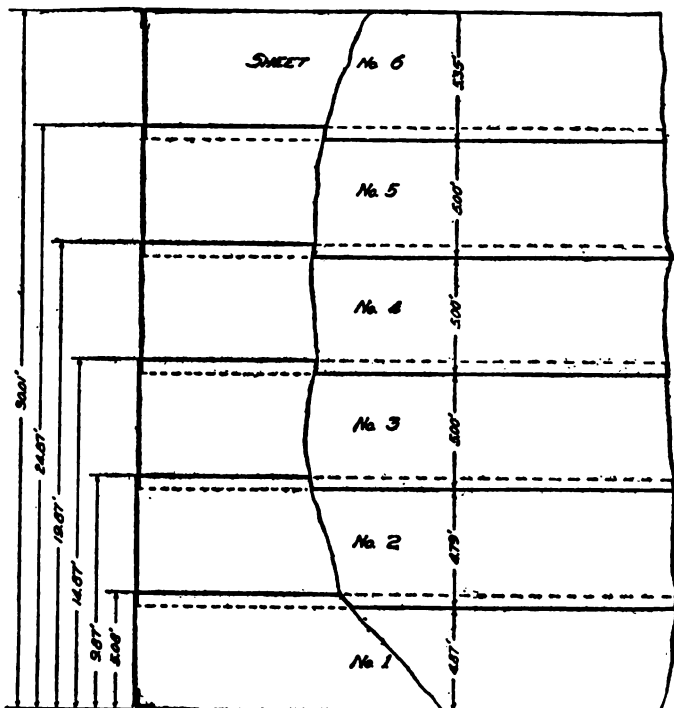


FIGURE 3.—Points between which various measurements for height of sheets apply.

near as practicable to the middle of the top ring. Other companies "strap"^a above each seam, and take one measurement 6 inches below the top of the tank, and one near the bottom just above the bottom row of rivets. However, it has been found that in measuring steel tanks of standard size a surprisingly small variation in results will be obtained if circumference measurements are taken on each ring, or if only the top and bottom rings are measured and the circumference

^a A term in general use among oil operators, originally meaning the girthing of tanks with a measuring tape, but in modern diction includes the whole operation of obtaining the necessary field data for computing the volume of tanks and other fluid receptacles.

of the others computed. On the other hand, tanks on poor foundations causing them to be "out of round" and producing bulging uneven sides may require a large number of measurements to insure accuracy. Although it is difficult to lay down any fixed rules that will apply to all classes of tanks it is believed that the following form of field notes includes sufficient data for reasonably accurate results. A 55,000-barrel tank has been assumed in which the roof supports consist of wooden posts tied together with sway bracing and resting on footing blocks, as this is the most complicated form of construction so far as volumetric computations are concerned. The points between which the various measurements for height of sheets apply are shown in figure 3.

RECORD OF FIELD NOTES SHOWING MEASUREMENTS NECESSARY FOR COMPUTING VOLUMES OF STEEL TANKS.

Location of tank: Party:
Size of tank: Date:

Measurements of tank^a by courses.

Item.	Course No. ^b					
	1	2	3	4	5	6
Circumference, feet.....	360.37	360.17	360.09	^c 360.13	^c 360.17	360.22
Number of sheets, feet.....	26	26	26	26	26	26
Lap of vertical seam, feet.....	.19	.19	.19	.19	.17	.12
Lap of horizontal seam, feet.....	.21	.21	.21	.21	.21	.....
Horizontal segment, feet.....	2.50	2.00	2.00	^c 1.58	^c 1.17	.67
Thickness of sheet, inches.....	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$
Thickness of sheet, feet.....	.05	.04	.05	.02	.02	.02
Bottom of tank to top of sheet (outside), feet.....	5.08	9.87	14.87	19.87	24.87	^d 30.01
Edge to edge of sheet (inside), feet.....	4.87	4.79	5.00	5.00	5.00	^d 5.35

^a Bottom angle iron, $\frac{1}{2}$ inch by 4 inches by 4 inches; measurements taken approximately in center of courses.

^b Courses numbered from bottom of tank upward.

^c Calculated.

^d Top of top angle iron.

DEADWOOD.

Footing blocks:

Outside circle posts, 22 pieces, 2 inches by 8 inches by 2 feet. Bottom of tank to 2 inches.

Third circle posts, 12 pieces, 2 inches by 8 inches by 2 feet. Bottom of tank to 2 inches.

Third circle posts, 2 pieces, 2 inches by 8 inches by 2 feet. Bottom of tank from 2 inches to 4 inches.

Second circle posts, 10 pieces, 2 inches by 8 inches by 2 feet. Bottom of tank to 2 inches.

Center circle posts, 2 pieces, 2 inches by 8 inches by 12 $\frac{1}{2}$ feet. Bottom of tank to 2 inches.

Center circle posts, 2 pieces, 2 inches by 8 inches by 12 $\frac{1}{2}$ feet. Bottom of tank, from 2 inches to 4 inches.

Bottom ties:

Outside circle posts, 2 pieces, 2 inches by 8 inches by 15 feet 4 inches. From 4 inches to 12 inches.

Bottom ties—Continued.

Third circle posts, 1 piece, 2 inches by 8 inches by 16 feet 8 inches. From 6 inches to 14 inches.

Second circle posts, 2 pieces, 2 inches by 8 inches by 15 feet. From 2 inches to 10 inches.

Swing-pipe rest:

1 piece, 1½ inches by 8 inches by 13 feet. From 12 inches to 20 inches.

2 pieces, 1½ inches by 8 inches by 20 inches. From 2 inches to 20 inches.

2 pieces, 2 inches by 8 inches by 24 inches. From bottom of tank to 24 inches.

2 pieces, 1½ inches by 8 inches by 20 inches. From 23 inches to 24½ inches.

Sway bracing:

Outside circle posts, 48 pieces, 1 inch by 6 inches by 24 feet. From 3 feet to 21 feet 8 inches.

Third circle posts, 30 pieces, 1 inch by 6 inches by 23 feet. From 3 feet to 20 feet 5 inches.

Second circle posts, 20 pieces, 1 inch by 6 inches by 22 feet. From 3 feet to 22 feet.

Center circle posts, 4 pieces, 1 inch by 6 inches by 18 feet 6 inches. From 4 inches to 14 feet.

Center circle posts, 4 pieces, 1 inch by 6 inches by 18 feet. From 4 inches to 13 feet 5 inches.

Center circle posts, 2 pieces, 2 inches by 8 inches by 14 feet 6 inches. From 13 feet 5 inches to 14 feet 1 inch.

Girders:

Outside circle posts, 24 pieces, 5 inches by 12 inches by 15 feet. From 28 feet 6 inches to 29 feet 6 inches.

Knee braces:

Outside circle posts, 12 pieces, 2 inches by 8 inches by 6 feet. From 24 feet 5 inches to 28 feet 6 inches.

Third circle posts, 16 pieces, 2 inches by 8 inches by 6 feet. From 27 feet 4 inches to top (45°).

Second circle posts, 10 pieces, 2 inches by 8 inches by 6 feet. From 28 feet 6 inches to top (45°).

Posts:

Outside circle, 24 pieces, 6 inches by 6 inches. From 4 inches to 28 feet 4 inches.

Third circle, 16 pieces, 6 inches by 6 inches. From 4 inches to top.

Second circle, 10 pieces, 6 inches by 6 inches. From 2 inches to top.

Center circle, 4 pieces, 6 inches by 6 inches. From 4 inches to top.

Rafts: 120, 2 inches by 8 inches.

Distance from bottom of tank to bottom of rafter at center of tank, 36 feet 6 inches.

Top of rafter at shell flush with top of top angle iron.

Manhole, 23½ inches in diameter by 6 inches deep. Bottom, 20 inches above bottom tank.

METHODS OF MEASURING.

The outside measurements should be taken in feet and hundredths, the most convenient form in which to have the data for computations. Measurements of deadwood, by which is meant all material inside the tank that displaces oil, such as roof supports, blocking, steam coils, and water draw-off pipes, are usually more conveniently taken in feet and inches, as the parts mentioned usually consist of standard-sized timbers and pipes.

The circumference measurements are taken as nearly as possible in the center of each course with the exception of courses 4 and 5 (count-

ing from the bottom upward), which can be more accurately calculated by interpolating between the girths of courses 3 and 6 than by actual measurement. The circumference of the top course is taken by reaching down over the eaves of the tank, the tapeman lying face down on the roof.

If possible, inside measurements should be taken before any oil is put into the tank. Outside measurements should be taken when the tank is full of oil.

After one set of dimensions has been taken it is checked by taking a second set in exactly the same manner. The maximum permissible difference in these two sets of measurement should not be more than 1 in 10,000.

MEANING OF TERMS.

HEIGHT OF TANK.

The height of a tank for strapping purposes is the distance between the top of the bottom plate of the tank and the top of the horizontal leg of the top angle iron.

HORIZONTAL SEGMENT.

By the horizontal segment is meant the part of the tank shell, less the vertical lap, which encroaches on the area inclosed by a circle, the plane of which is parallel to the tank bottom and the diameter of

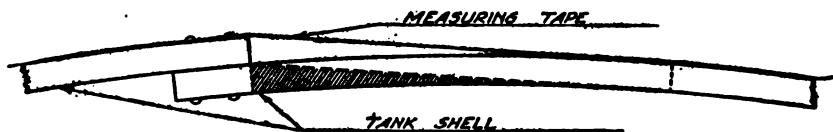


FIGURE 4.—Horizontal segment.

which is equal to the inside diameter of the tank. The hatched part in figure 4 shows the horizontal segment, which is approximately equal in area to the triangle made by the tape and the tank shell. The horizontal segment is not considered at all by many operators and by others is used only when very accurate results are required.

THICKNESS OF SHEETS.

The thicknesses of the sheets in the various rings can usually be most accurately and most easily determined from the specifications of the tank.

DEADWOOD.

The swing pipe and fittings and the water draw-offs in the bottom of the tank are usually omitted for the reason that they are always full of oil or water whenever a gage of the tank is taken, and the metal of which they are composed will at most displace only a small volume of liquid. To guard against the possibility of the swing pipe being empty or only partly filled when a gage of the tank is taken, some companies install on the shell of the tank about 2 feet from the

swing-pipe nozzle a 2-inch flange having its center line on approximately the same horizontal plane as the center line of the nozzle. A 2-inch pipe connection containing a valve is then placed between this flange and the nozzle, so that oil may be admitted from a point near the bottom of the tank into the bottom of the swing pipe whenever desired. Sand lines are also omitted. However, if there are steam coils in the tank, their volume must be deducted.

MANHOLE.

The dimensions of the manhole should be determined, as also its position, as the volume of oil that it contains must be added to the volume of the tank.

CORRUGATED-IRON AND WOODEN TANKS.

As regards corrugated-iron tanks, which are usually of small diameter, the circumference measurements are obtained with the tape lying in the valley of the corrugation. The depth of the corrugation and the distance between corrugations are noted.

In strapping wooden tanks with sloping sides, the thickness of the staves is taken at a number of places about the circumference, and an average thickness determined. The height is obtained by placing a gage rod inside the tank and measuring the vertical height to the top of the staves. The circumference strappings are taken at intervals of 2 feet, measured along the slope of the tank, beginning 6 inches from the bottom.

COMPUTING GAGE TABLES FOR TANKS.

From the circumference of each course the outside diameter of that course is computed, and by subtracting twice the thickness of the metal the inside diameter is determined, giving a value from which the gross area of the course is determined. From this is subtracted one-half the area of the vertical laps and the area of the horizontal segments, giving the net area (plus the deadwood). As the circumference is measured approximately in the center of the sheet, the net area value is considered to be a mean area for the course.

The volume in barrels per course, including the deadwood, is then calculated and the volume in barrels per one-fourth inch per course. Next the volume of the deadwood per course is determined and the volume of the deadwood per one-fourth inch per course. Then a table is prepared showing the quantity in barrels to be added for each one-fourth of an inch proceeding from the bottom of the tank upward. The construction of the gage table then resolves itself into the summation of the proper increments. If it were desired to have the gage table read to one-eighth inch the same method of computation would be pursued. In buying and selling crude oil it is customary to read the gage tape to the nearest one-eighth of an inch and interpolate in the table to find the correct volume.

Each step in the computations should be carefully checked. **One-fourth inch totals must equal totals for courses calculated by subtracting the volume of the total deadwood in the course from the total volume of the course, and totals of courses must agree with a separate computation for the whole tank in which figures for total tank volume and total deadwood are used.**

As a final check on the whole work a second man is required to make an independent calculation not quite so complete as the first but one that must check the total contents of each course and the total contents of the tank. Gage tables are made to read to the nearest one-hundredth of a barrel.

RESERVOIR MEASUREMENT AND TABLES.

For the convenience of the gager a small hatch is placed in the roof of the tank, usually near the head of the stairway. The gage tape is suspended through the hatch into the open tank. However, as regards reservoirs, it is customary to set what is known as a gage plate at some convenient place as close as practicable to the lowest point in the bottom of the reservoir and to take all measurements for depth of oil from this plate. It comprises a steel plate about $\frac{1}{2}$ inch thick and 3 feet square, which is set with foundation bolts and carefully leveled and grouted. This work is done as the part of the floor in that vicinity is being constructed so that it becomes an integral part of the lining. Some companies use a smaller gage plate and place on it a vertical pipe 4 to 10 inches in diameter of sufficient length to extend out through the roof of the reservoir. The walls of the pipe are perforated or slotted, and the top is fitted with a cap. Measurements for depth of oil are then taken through the pipe.

TESTING GAGE PLATE.

One of the first duties of the field or construction engineer in procuring the data necessary for the preparation of a gage table for the reservoir is to examine carefully the gage plate and determine whether all the foundation bolts are tight, and whether the plate has been properly grouted and has not sprung at any point, but is absolutely level over its entire surface. The following information should then be procured:

NECESSARY MEASUREMENTS IN TESTING GAGE PLATE.

1. The diameter at the toe of the inner slope.^a
2. The diameter at the top of the inner slope.^a
3. The elevation of the gage plate.
4. The elevation of a sufficient number of points on the bottom so that an accurate contour map may be plotted, the contour interval of which should be not more than one-fourth of an inch.

^a This measurement should be taken in as many places as possible and carefully checked.

5. The dimensions of all footings, posts, braces, and other deadwood as outlined for tank strappings.^a

4. The location and the size of the sump containing the swing pipes and water draw-off pipes.

COMPUTING GAGE TABLE.

From the elevation of the points on the bottom of the reservoir a contour map of one-fourth inch interval is plotted and from this the gross content up to the gage plate is computed. To this is added the volume of the sump and from the sum is subtracted the volume of the deadwood up to the plane of the gage plate. The net amount thus obtained gives the content of the reservoir up to 0 feet 0 inches on the gage table.

If the gage table is to read to one-eighth of an inch, as is usually the case, the content is computed in a similar manner proceeding by eighths of an inch, up to the point where a horizontal plane will cut the side slopes of the reservoir. From this point to the top the volume is computed at one-eighth inch intervals, the reservoir being considered as a frustrum of a cone, deadwood being deducted as in the tank-table computations.

Gage tables are made to read to the nearest one-hundredth of a barrel. Volumes for fractions of an inch less than one-eighth are obtained by interpolation.

DEPRECIATION OF OIL IN STORAGE.

Table 7 shows comparative results of distillations of various fresh crude oils and oils from the same fields after being in storage for a period of years. The table indicates that practically every oil showed a considerable loss in the total proportion distilled from the stored liquid and that this loss reached its maximum at an end point of about 150° C.

Table 8 shows comparative results of tests on fresh and stored heavy California crude. The ultimate test showed that this low-gravity oil although having remained in storage for a period of six years seemingly had not lost in fuel value.

Although the samples of fresh and stored oil were taken from the same fields and as nearly as possible from the same wells, the fresh-oil samples were not, unfortunately, taken and analyzed at the time the oil was put in storage; on the contrary they were taken from the wells at the end of the storage period. The fact that the composition of oil produced by a given field often changes somewhat from time to time may account for seeming discrepancies in some of the figures.

^a As regards a reservoir, however, on account of the slope to the bottom, the exact location of the deadwood must also be determined.

OSAGE CRUDE.

[Stored crude in storage 7 years 8 months.]

Up to 75.	2.2	2.2	81.0	.....	0.0	.....	2.2	.....	2.2	.....	Gravim., ° B.	33.7	.....	31.2
75 to 100.	3.7	5.9	64.0	1.6	1.6	.....	2.1	.....	4.3	.....	Flash point, ° F.	Below 75.	.....	Below 75.
100 to 125.	4.2	10.1	58.0	3.2	4.8	56.2	1.0	.....	5.3	.....	Fire point, ° F.	Below 75.	.....	Below 75.
125 to 150.	4.2	14.3	53.0	4.2	9.0	51.5	.....	.....	5.2	.....	Sand	None	.....	None
150 to 175.	5.0	19.3	48.2	4.4	13.4	47.0	.....	.....	5.9	.....	Water	None	.....	None
175 to 200.	4.0	23.3	45.0	3.8	17.2	43.8	.....	.....	6.1	.....	Viscosity at 20° C., ° Engler	1.9	.....	2.5
200 to 225.	5.4	28.7	41.5	5.3	22.5	40.5	.....	.....	6.2	.....	Cold test at 0° C.	Liquid	.....	Liquid
225 to 250.	6.0	34.7	38.5	6.8	29.3	38.0	.....	.....	.....	.....	.....	.....	.....	.....
250 to 275.	6.5	41.2	36.0	7.0	36.3	35.4	.....	.....	.....	.....	.....	.....	.....	.....
275 to 300.	5.8	47.0	34.5	9.0	45.3	34.5	.....	.....	3.2	.....	.....	.....	.....	.....

BARTLESVILLE CRUDE.

[Stored crude in storage 4 years 3 months.]

Up to 75.	2.1	2.1	.....	.....	0.0	.....	2.1	.....	2.1	.....	Gravim., ° B.	30.7	.....	29.6
75 to 100.	3.1	6.2	57.5	1.4	1.7	.....	1.1	.....	2.2	.....	Flash point, ° F.	Below 72.	.....	118.
100 to 125.	3.0	9.5	46.7	3.8	4.7	54.0	.....	.....	4.8	.....	Fire point, ° F.	Below 72.	.....	138.
125 to 150.	3.6	13.9	41.0	3.8	9.5	49.5	.....	.....	5.1	.....	Sand	None	.....	None
150 to 175.	4.1	18.3	41.0	3.8	13.0	45.3	.....	.....	4.4	.....	Water	Trace	.....	None
175 to 200.	4.5	23.3	40.8	6.0	19.0	42.0	.....	.....	5.4	.....	Viscosity at 20° C., ° Engler	2.7	.....	3.4
200 to 225.	4.8	28.7	38.2	6.8	25.8	38.8	.....	.....	4.3	.....	Cold test at 0° C.	Liquid	.....	Liquid
225 to 250.	5.5	35.0	36.0	7.0	32.8	36.2	.....	.....	2.2	.....	.....	.....	.....	.....
250 to 275.	6.2	43.5	34.8	9.2	42.0	35.5	.....	.....	1.5	.....	.....	.....	.....	.....
275 to 300.	8.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

NOWATA COUNTY, OKLA., CRUDE.

[Stored crude in storage 7 years 4 months.]

Up to 75.	2.0	2.0	.....	.....	0.0	.....	2.0	.....	2.0	.....	Gravim., ° B.	32.0	.....	30.1
75 to 100.	1.2	6.8	59.0	1.5	1.5	.....	1.2	.....	3.2	.....	Flash point, ° F.	Below 70.	.....	115.
100 to 125.	3.6	11.3	55.0	4.0	5.5	51.5	.....	.....	5.3	.....	Fire point, ° F.	Below 70.	.....	162.
125 to 150.	4.5	16.3	50.2	4.6	10.1	47.3	.....	.....	5.8	.....	Sand	None	.....	None
150 to 175.	5.0	21.5	46.3	3.7	13.8	44.0	.....	.....	6.2	.....	Water	Trace	.....	None
175 to 200.	5.2	26.4	43.0	5.5	19.3	41.5	.....	.....	7.7	.....	Viscosity at 20° C., ° Engler	2.4	.....	3.5
200 to 225.	4.9	33.8	39.8	7.0	38.8	38.8	.....	.....	7.1	.....	Cold test at 0° C.	Liquid	.....	Slightly viscous.
225 to 250.	5.3	37.7	37.0	7.5	33.8	36.8	.....	.....	1.7	.....	.....	.....	.....	.....
250 to 275.	6.6	45.1	35.0	8.7	42.5	35.5	.....	.....	4.5	.....	.....	.....	.....	.....
275 to 300.	6.8	.....	.....	.....	.....	.....	.....	.....	2.6	.....	.....	.....	.....	.....

TABLE 8.—Results of comparative tests of fresh and of stored California crude.

DISTILLATION TESTS.

Temperature.	Fresh crude.			Crude stored for 6 years.			Fractions, per cent by weight.		Loss in total proportion distilled.
	Fractions, per cent by weight.	Total per cent distilled.	Gravity.	Fractions, per cent by weight.	Total per cent distilled.	Gravity.	Loss.	Gain.	
°C.			°B.			°B.			Per cent.
Up to 175..	1.0	1.0	38.2	0.7	0.7	37.0	0.3	.....	0.3
175 to 200..	1.4	2.4		1.1	1.8		.3	.....	.6
200 to 225..	2.1	4.5		2.1	3.9		.0	.....	.6
225 to 250..	3.4	7.9	31.8	3.3	7.2	31.8	.1	.....	.7
250 to 275..	5.4	13.3	30.8	4.8	12.0	29.8	.6	.....	1.3

ULTIMATE TEST.

Oil.	Gravity at 60° F.	Viscosity 20° C.	Heating value per pound.	Water.	Sulphur.	Sand.	Flash point, Pensky-Martens tester, closed.	Burning point, Pensky-Martens tester, opened.	Remarks.
	°B.	°Engler.	B. t. u.	Per ct.	Per ct.	Per ct.	°F.	°F.	
Fresh.....	14.3	625	18,493	0.6	0.79	None..	188	325	Very viscous at 32° F.
Stored 6 years...	14.0	737	18,522	.6	.86	..do...	214	318	Do.

RÉSUMÉ.

In summing up it is well to repeat that the best all-around container in use at the present time for storing oil is the all-steel tank of gas-tight construction.

Tanks that are used for the accumulation of fresh oils from the well should invariably be of this construction, and as a rule it will probably pay to equip them with water-seal tops, if not also with some form of tile encasing or lagging.

Other devices for lessening the temperature of the oil in the tanks that can be cheaply applied and economically maintained, such as sprinkling with water in hot weather and painting the tanks white, are worth while.

To store gasoline or light distillate in tanks that have not tight tops is the height of folly, and it is poor judgment not to use also some type of cooling device.

Large concrete-lined reservoirs, as at present constructed, should not be used for the storage of fresh oils or of light oils.

It will pay to line a reservoir with concrete even though heavy oil only is to be stored.

In most cases it would probably also pay to put a concrete roof on the reservoir and cover it with earth—at least such a type of structure is worthy of consideration, no matter what the gravity of the oils to be handled.

Concrete, if properly proportioned, mixed, poured, tamped, and floated, can be made impervious to heavy oils without the addition of so-called "oil-proofing" compounds.

Contrary to popular engineering opinion, expansion joints are not necessary in properly constructed concrete linings for oil reservoirs in temperate climates, and no injury will result to the linings from their omission if the reservoirs be kept reasonably full of oil, or if, when the tanks are not in use, they are kept partly filled with water.

If crude can be refined at any profit, it should be put through the refinery as soon as possible after it is taken from the wells. If refining will not pay, the period of storage should be as short as possible because, so far as the oil is concerned, at best, each day of storage will entail a loss.

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